

2005

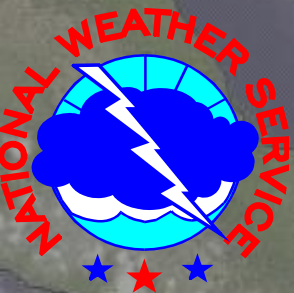
# Hurricanes and Global Warming: Expectations Versus Observations

12 June, 2015

NASA Jet Propulsion Laboratory

Chris Landsea, National Hurricane Center, Miami, USA

[Chris.Landsea@noaa.gov](mailto:Chris.Landsea@noaa.gov)





**UCLA**

**Atmospheric &  
Oceanic Sciences**



2005

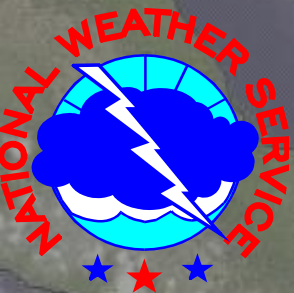
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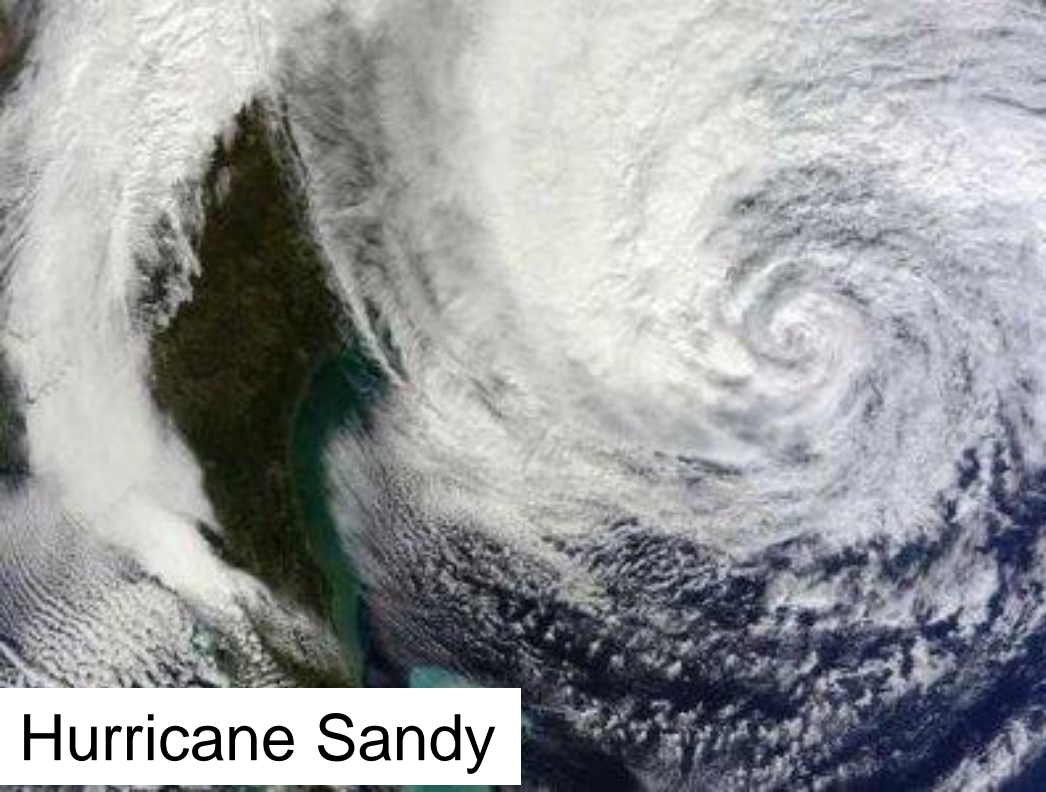
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Chris Landsea, National Hurricane Center, Miami, USA

[Chris.Landsea@noaa.gov](mailto:Chris.Landsea@noaa.gov)







Hurricane Sandy

**Bloomberg  
Businessweek**

# IT'S GLOBAL WARMING, STUPID





Bloomberg  
Businessweek

IT'S GLOBAL  
WARMING,  
STUPID

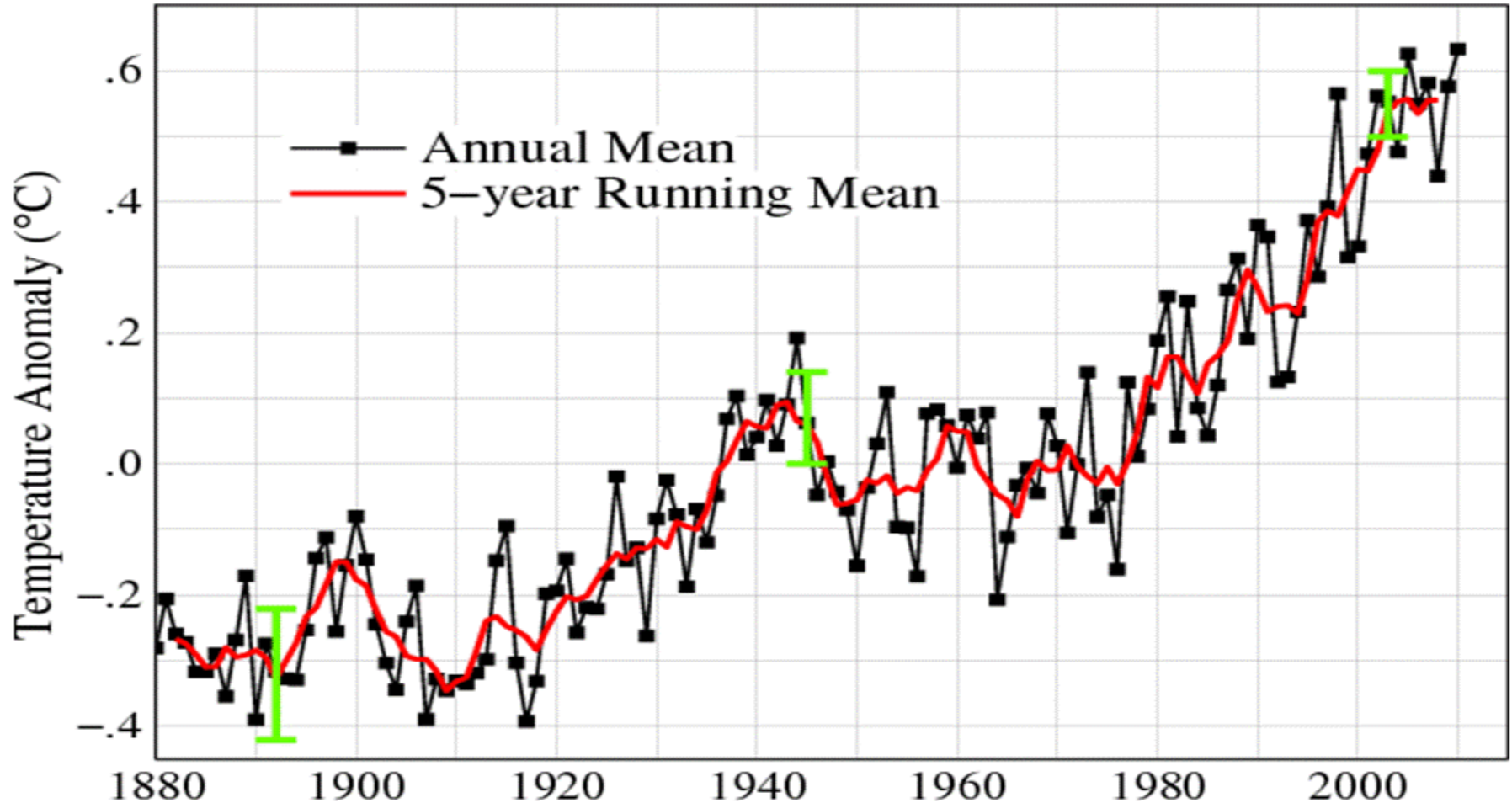
How is global warming affecting:  
Tropical cyclone frequency,  
intensity, genesis, track, and  
overall activity?

Hur



# Global Warming – Past Temperature Changes

Global Land–Ocean Temperature Index

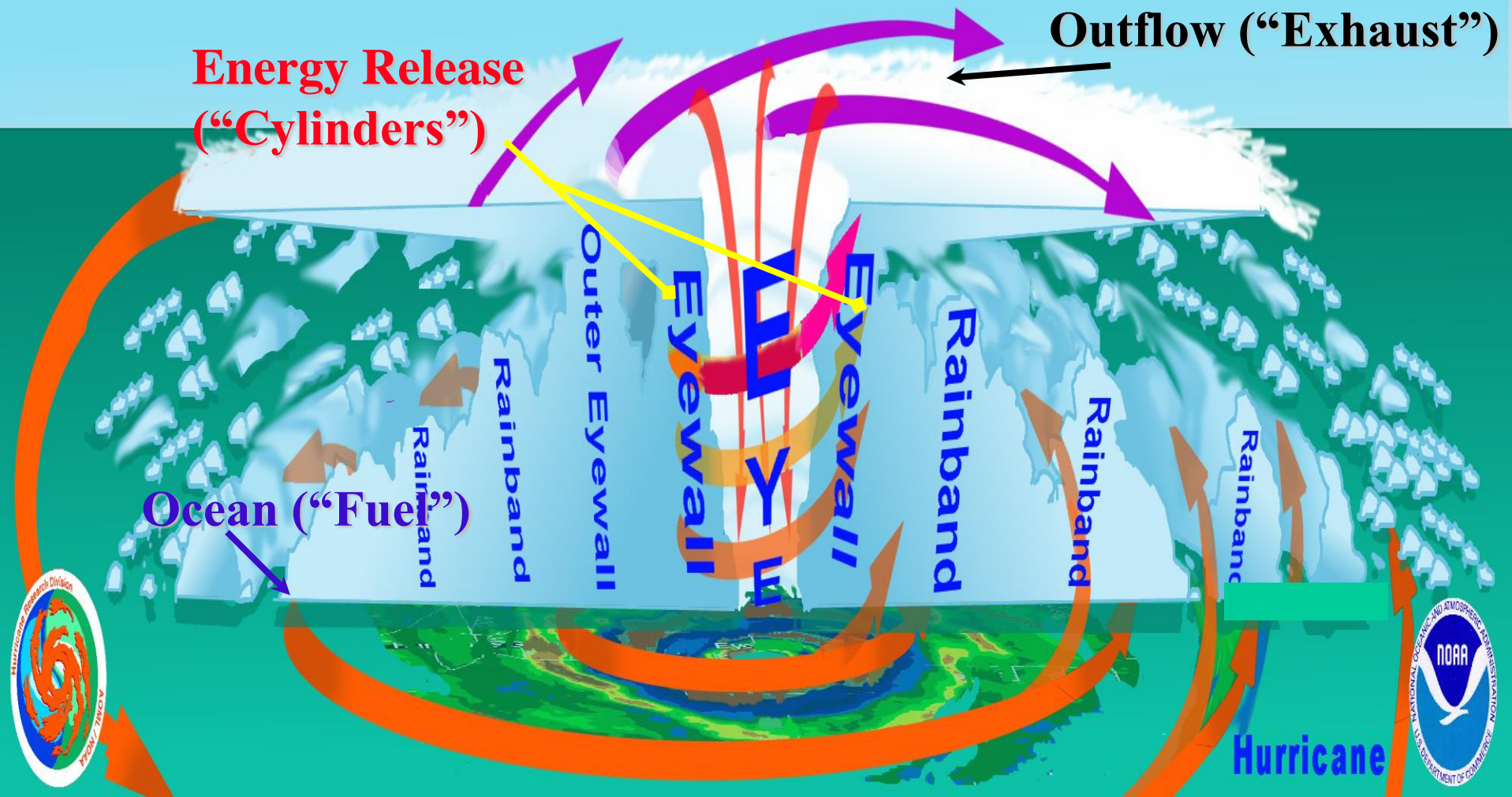


<http://data.giss.nasa.gov/gistemp/graphs/Fig.A2.gif>



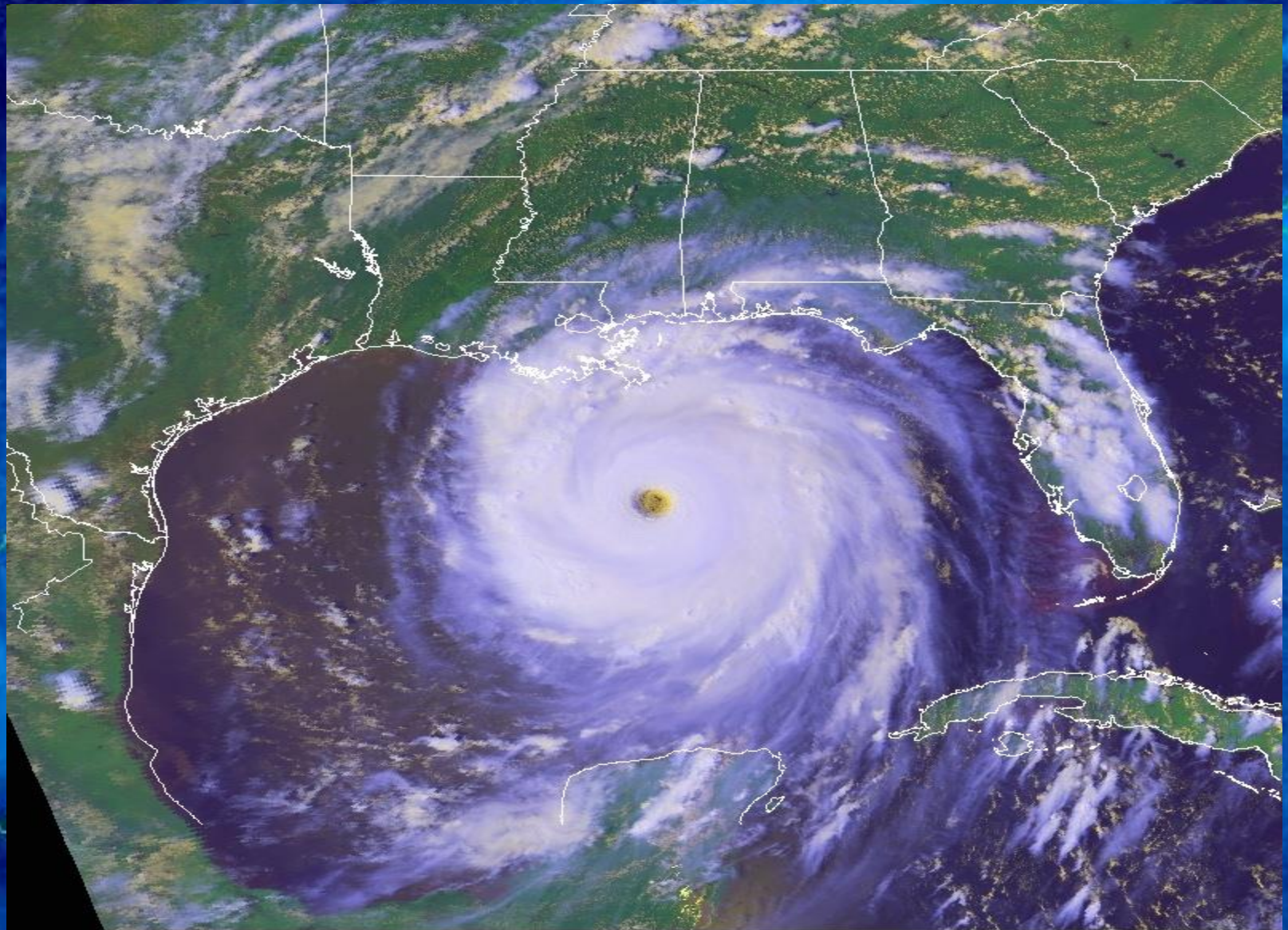
# Nature's great heat engine...

## The Hurricane





# Global Warming and Hurricane Winds: Theory and Modeling Work Suggest ~1% Increase Today



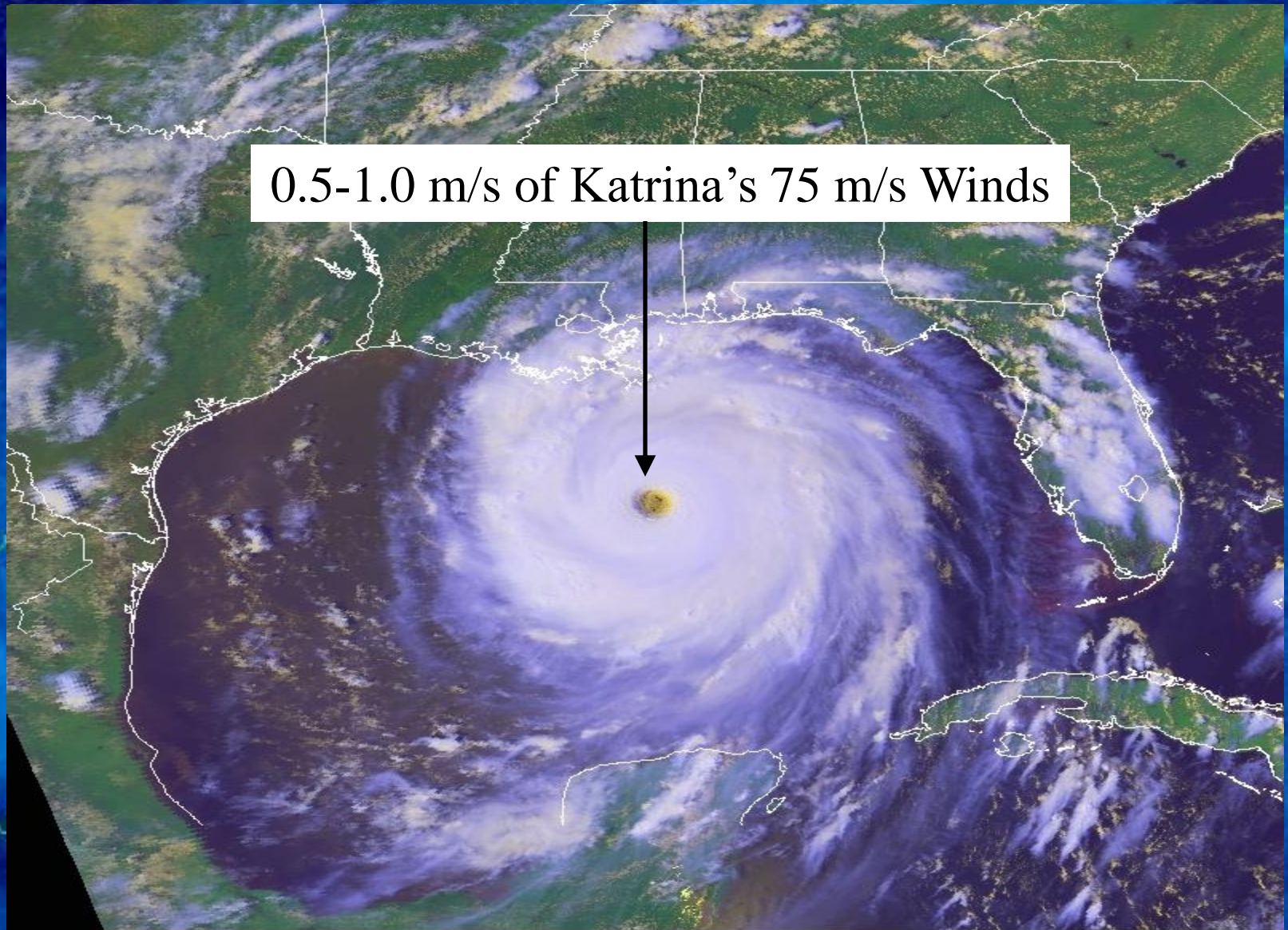
KATRINA NOAA-16 AVHRR 28 AUG 05 20:11 GMT  
UW-MADISON SPACE SCIENCE AND ENGINEERING CENTER

McIDAS



# Global Warming and Hurricane Winds: Theory and Modeling Work Suggest ~1% Increase Today

0.5-1.0 m/s of Katrina's 75 m/s Winds

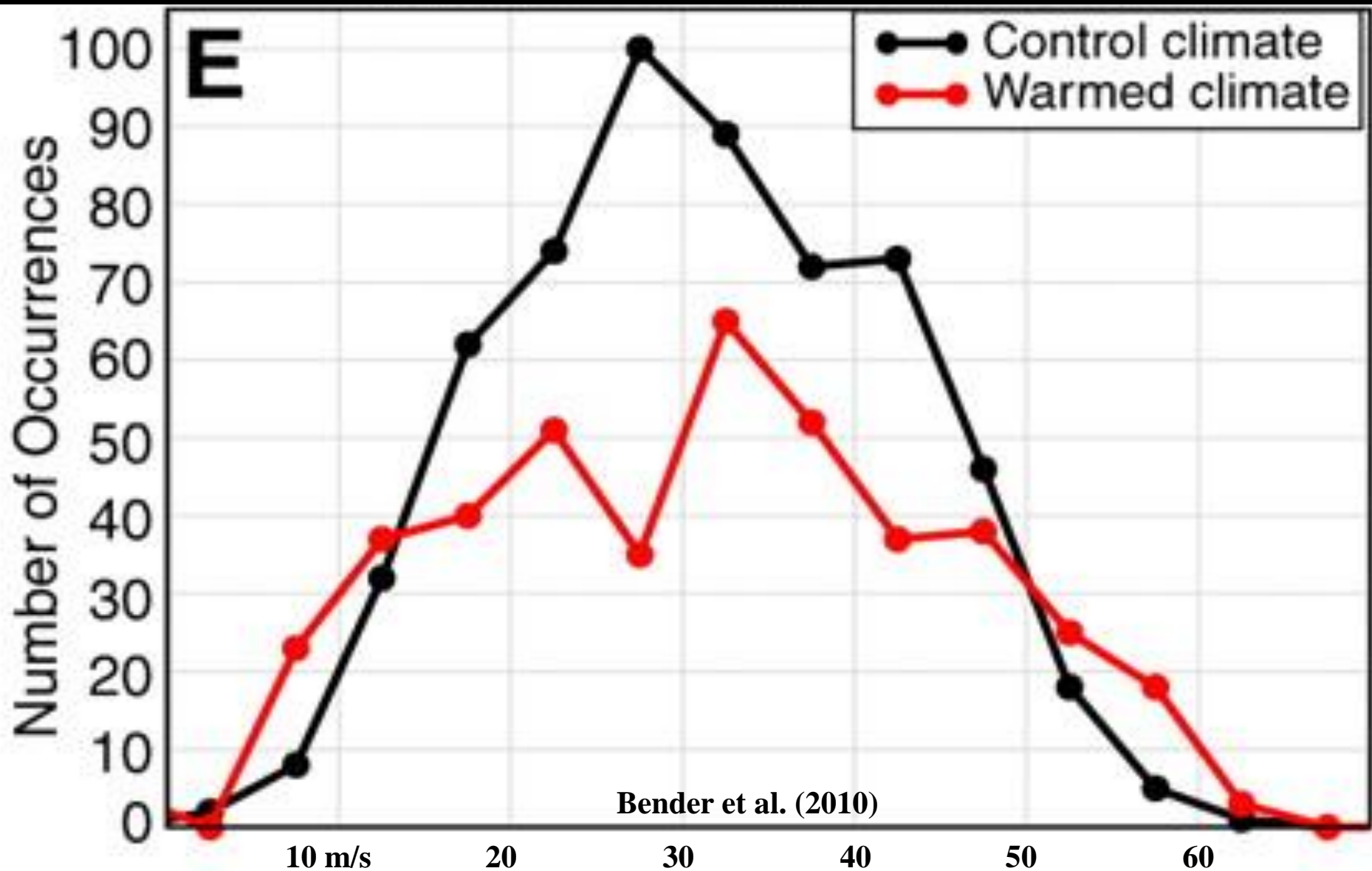


KATRINA NOAA-16 AVHRR 28 AUG 05 20:11 GMT  
UW-MADISON SPACE SCIENCE AND ENGINEERING CENTER

McIDAS

# Global Warming and Hurricanes:

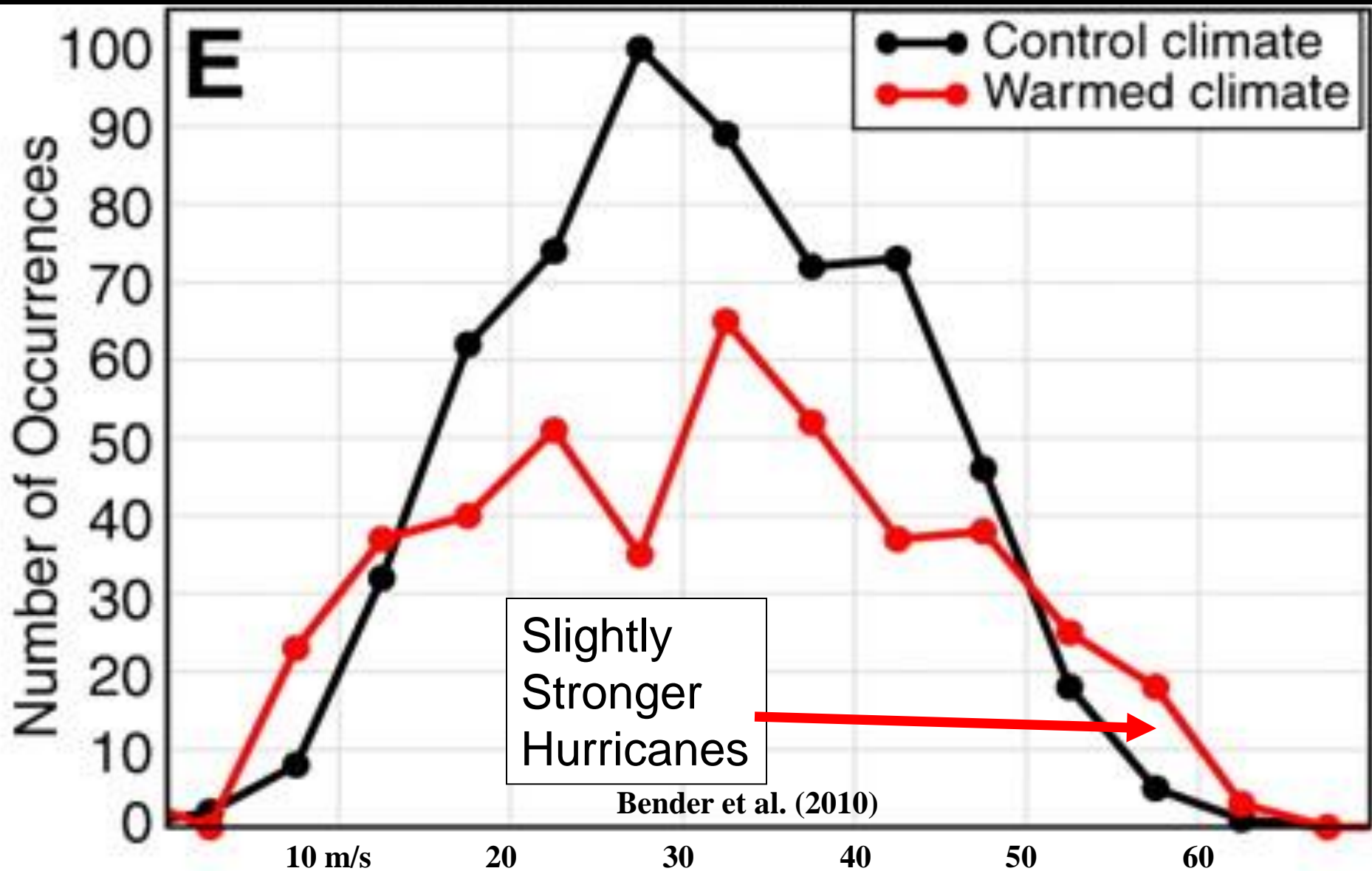
Theory and Modeling Work Suggest ~3% wind increase with a  
DECREASE in frequency by late 21<sup>st</sup> Century





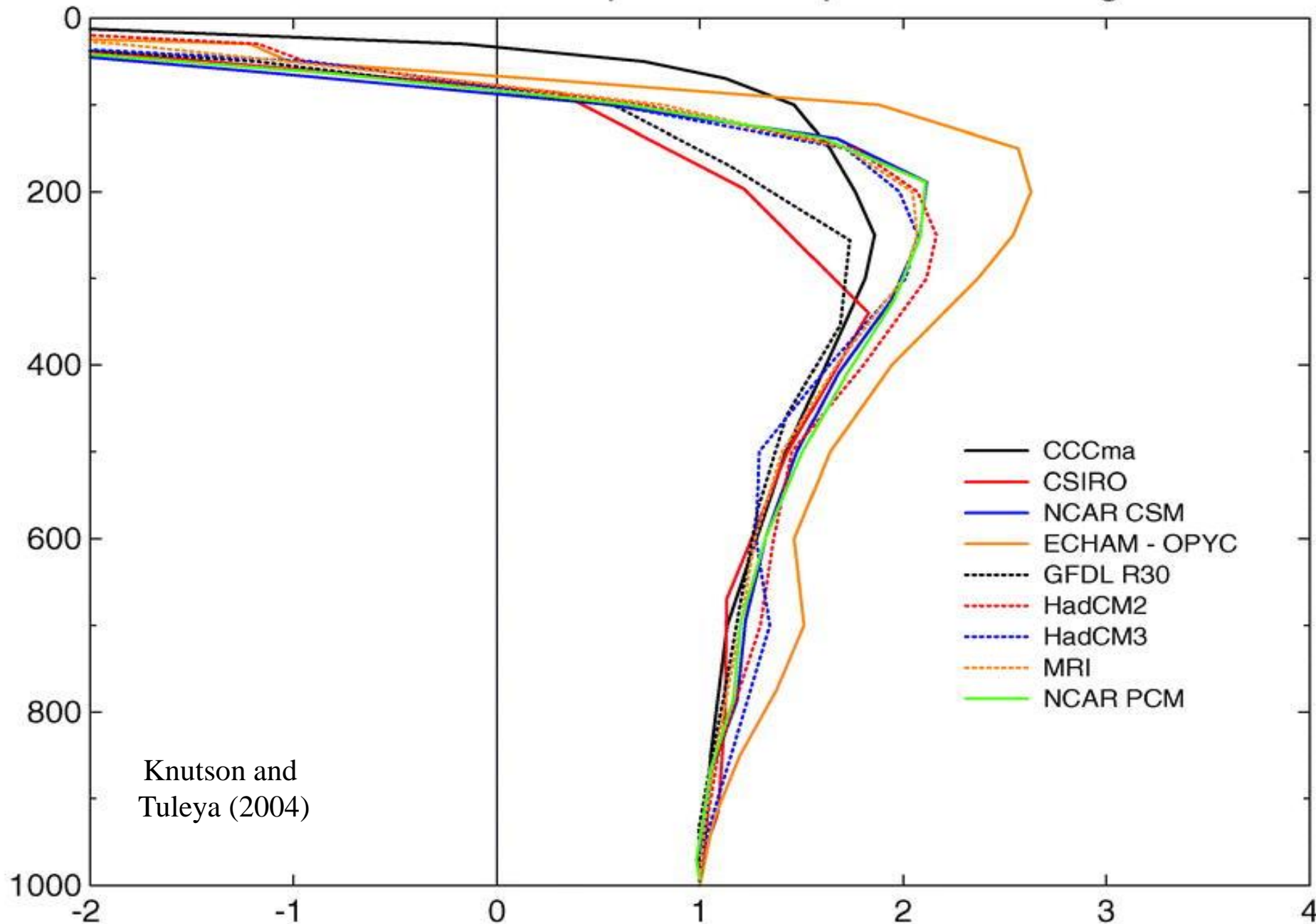
# Global Warming and Hurricanes:

Theory and Modeling Work Suggest ~3% wind increase with a  
DECREASE in frequency by late 21<sup>st</sup> Century



# Normalized Atmospheric Temperature Change

HPa

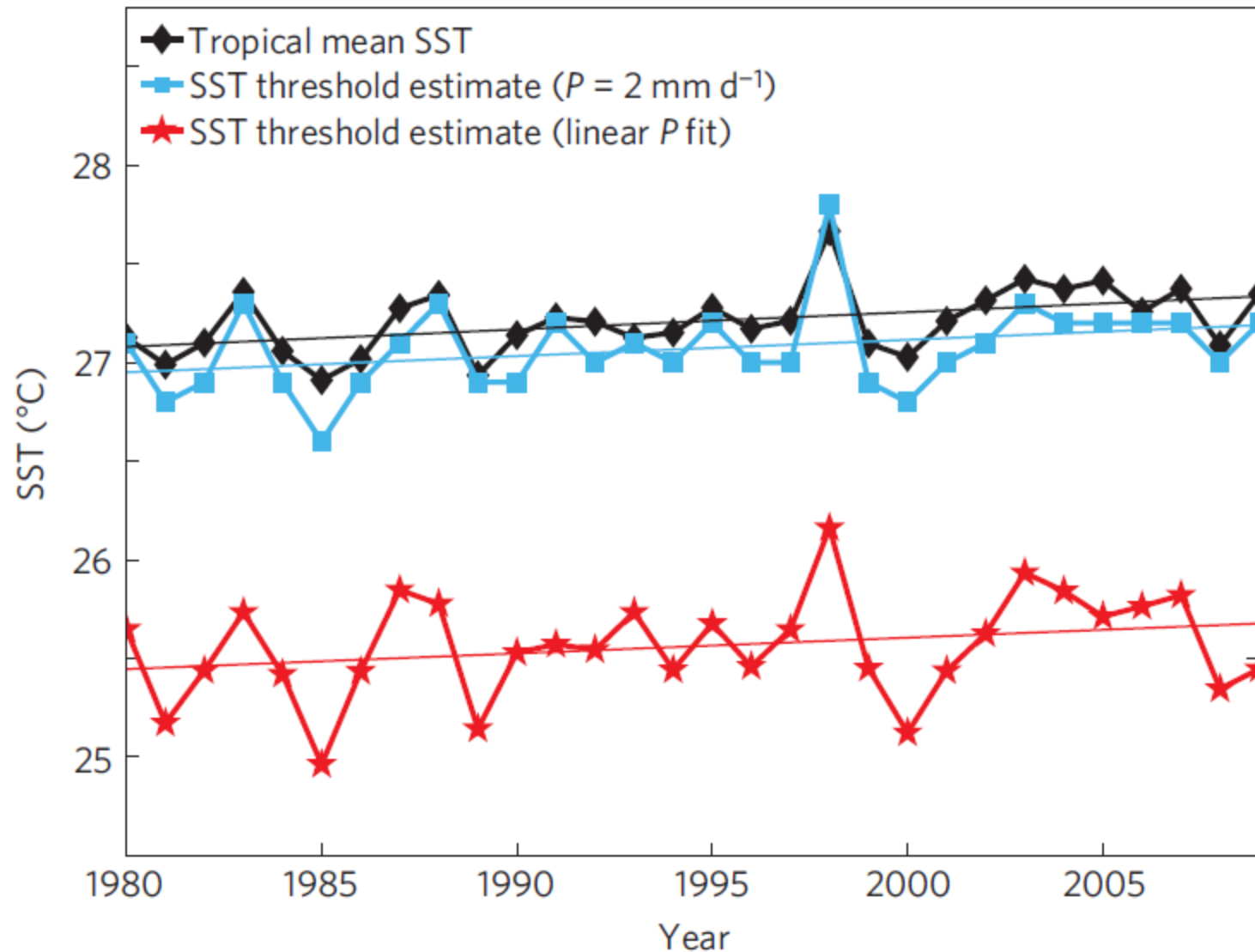


Knutson and  
Tuleya (2004)

Degrees per Degree Warming at Lowest Level

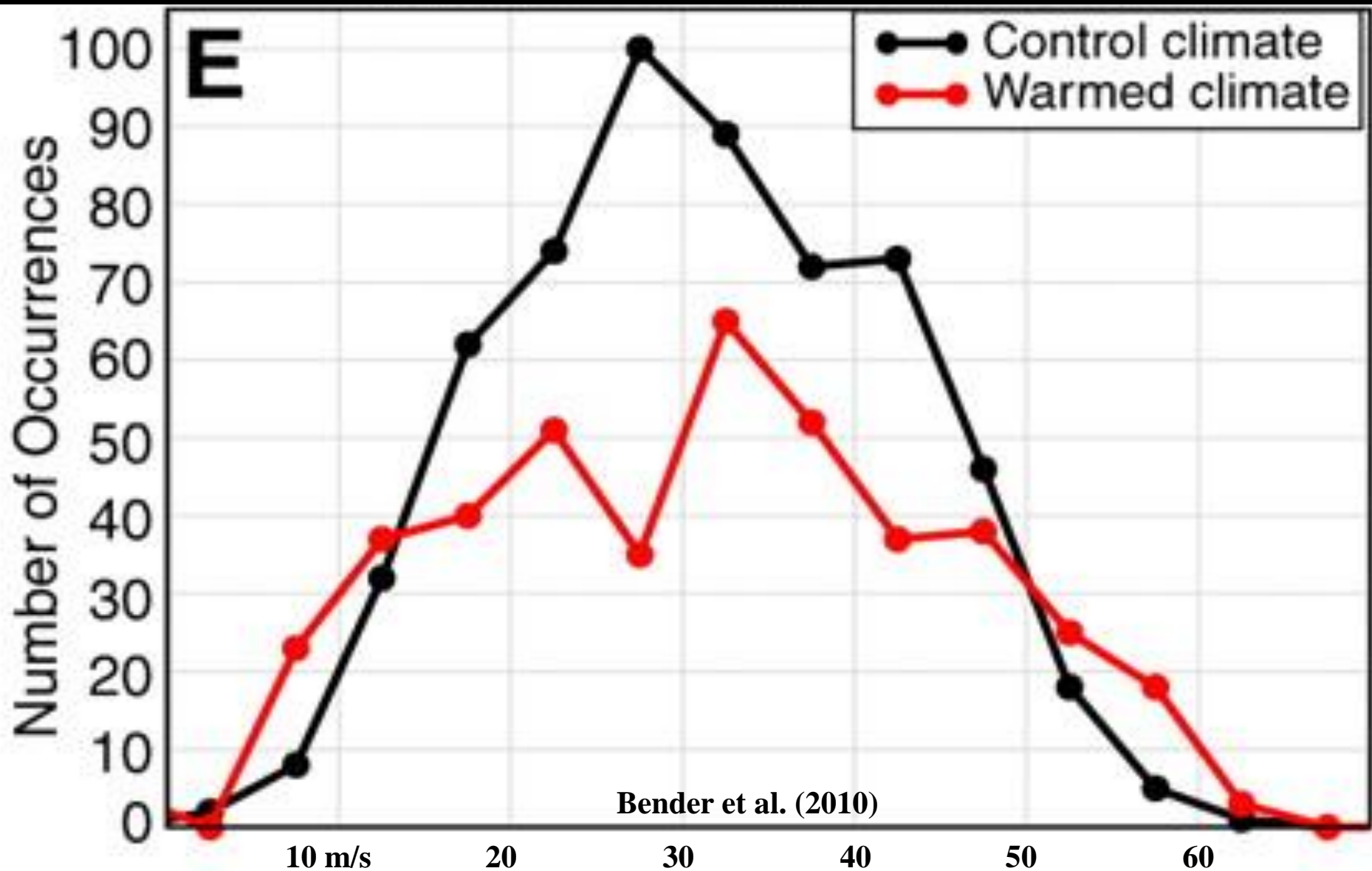


# Tropical Convection Changing with Global Warming



# Global Warming and Hurricanes:

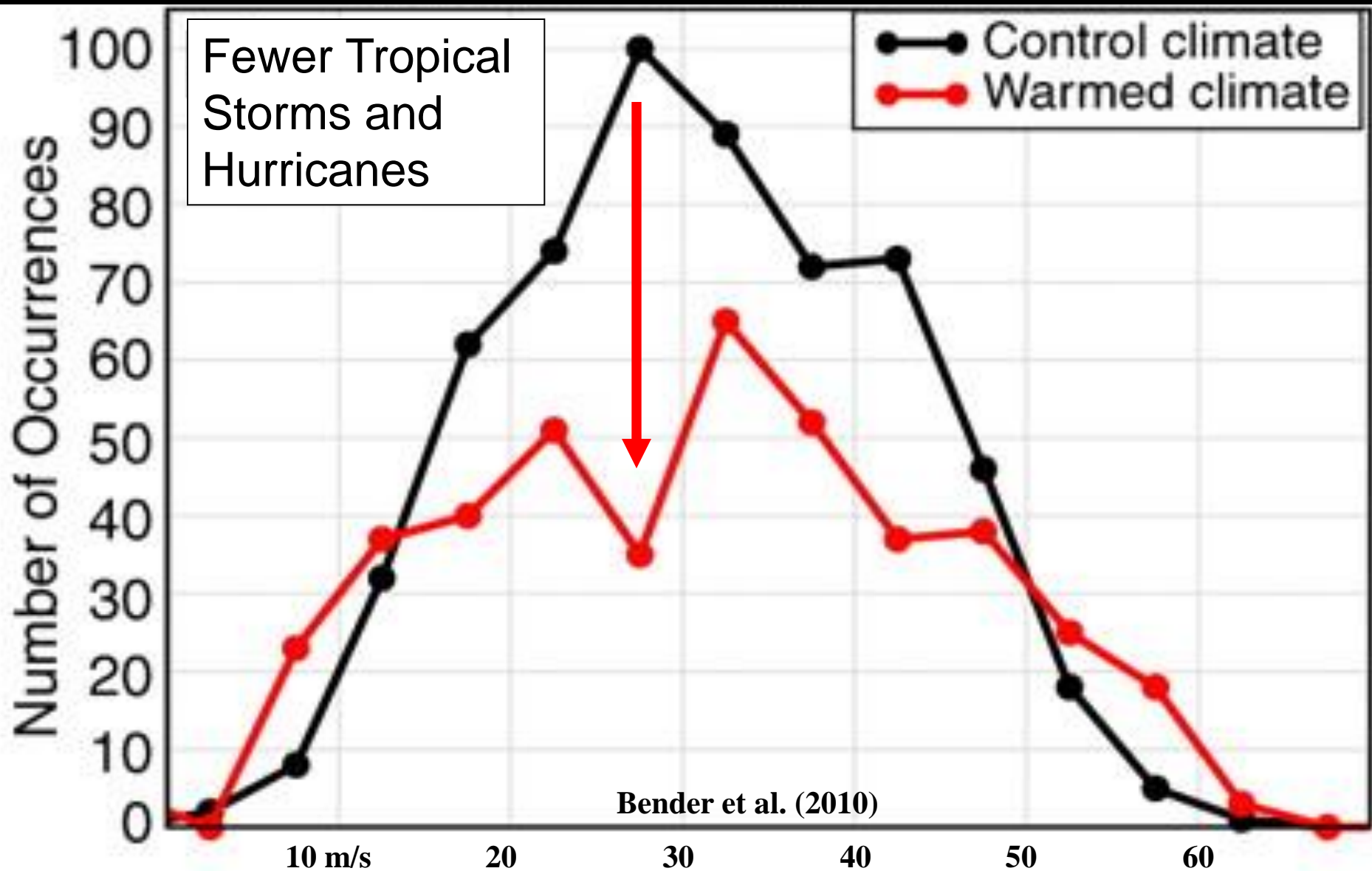
Theory and Modeling Work Suggest ~3% wind increase with a  
DECREASE in frequency by late 21<sup>st</sup> Century



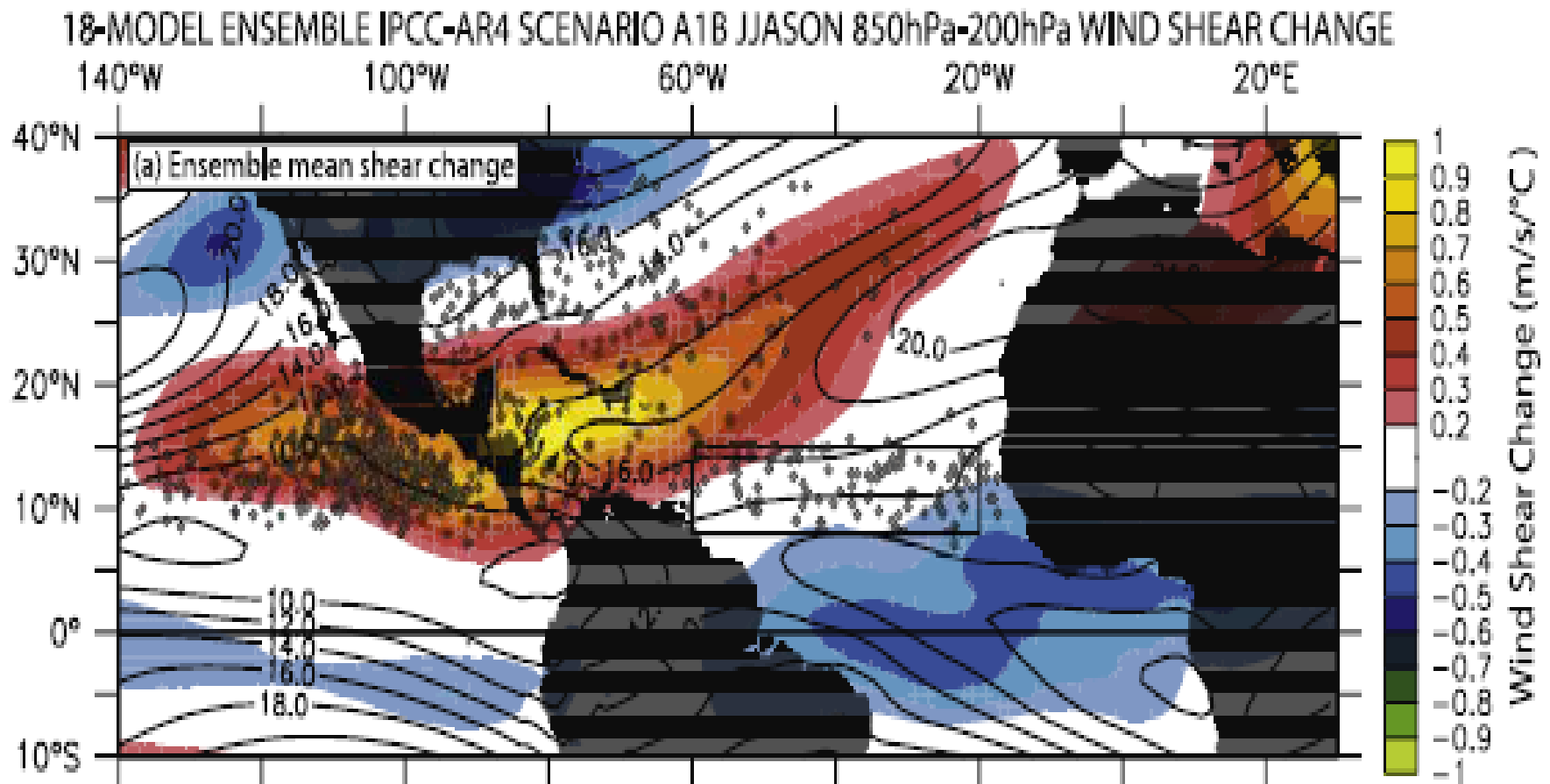


# Global Warming and Hurricanes:

Theory and Modeling Work Suggest ~3% wind increase with a  
DECREASE in frequency by late 21<sup>st</sup> Century



# Increased Wind Shear from Global Warming

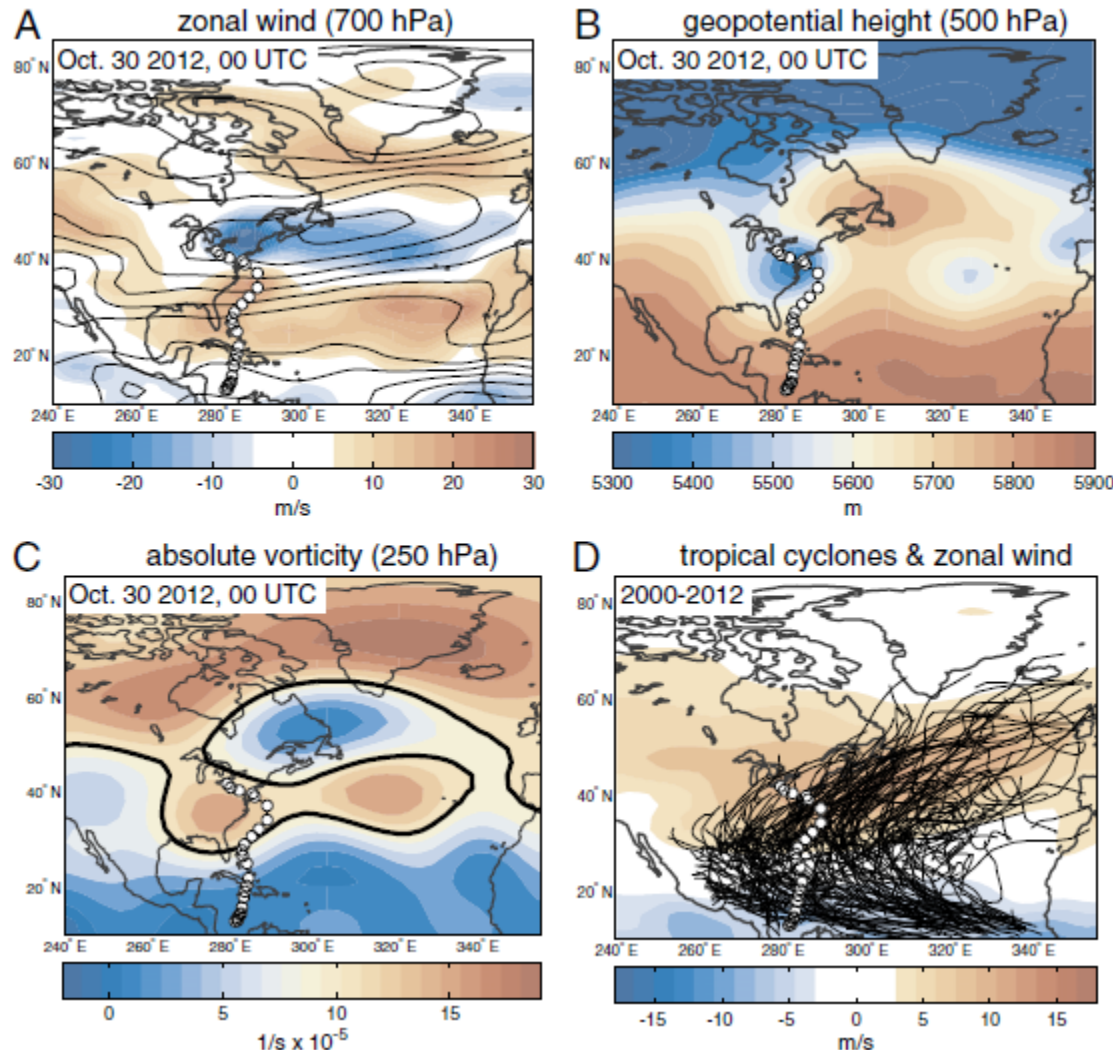


Vecchi and Soden (2007)



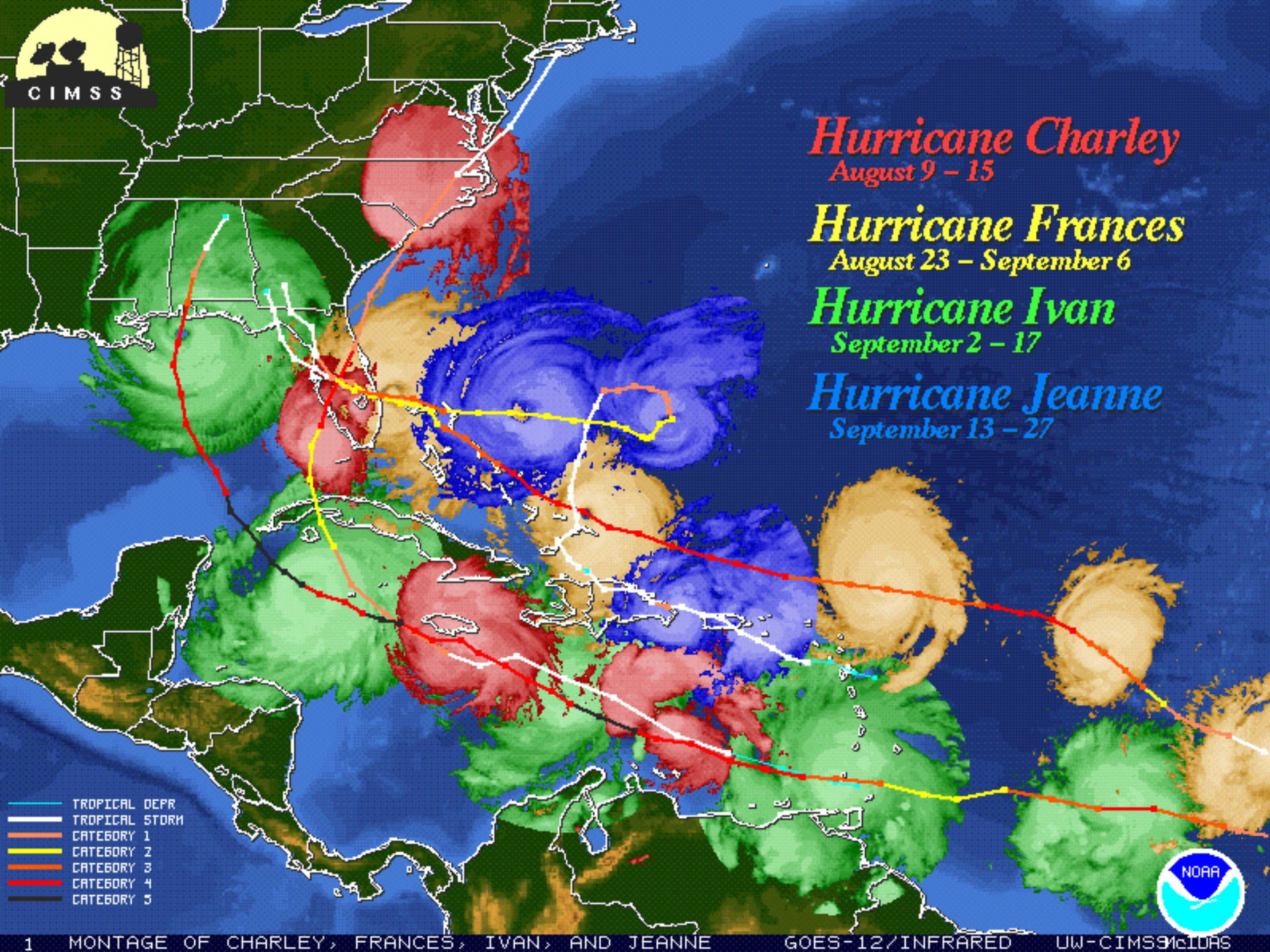
# Model projections of atmospheric steering of Sandy-like superstorms

Elizabeth A. Barnes<sup>a,b,1</sup>, Lorenzo M. Polvani<sup>b,c</sup>, and Adam H. Sobel<sup>b,c</sup>



“We demonstrate that climate models consistently project a decrease in the frequency and persistence of the westward flow that led to Sandy’s unprecedented track, implying that future atmospheric conditions are **less likely than at present to propel storms westward into the coast.**”





*Hurricane Charley*  
August 9 – 15

*Hurricane Frances*  
August 23 – September 6

*Hurricane Ivan*  
September 2 – 17

*Hurricane Jeanne*  
September 13 – 27

- TROPICAL DEPR
- TROPICAL STORM
- CATEGORY 1
- CATEGORY 2
- CATEGORY 3
- CATEGORY 4
- CATEGORY 5





2005

Rita  
23 September

Dennis  
10 July

Katrina  
28 August

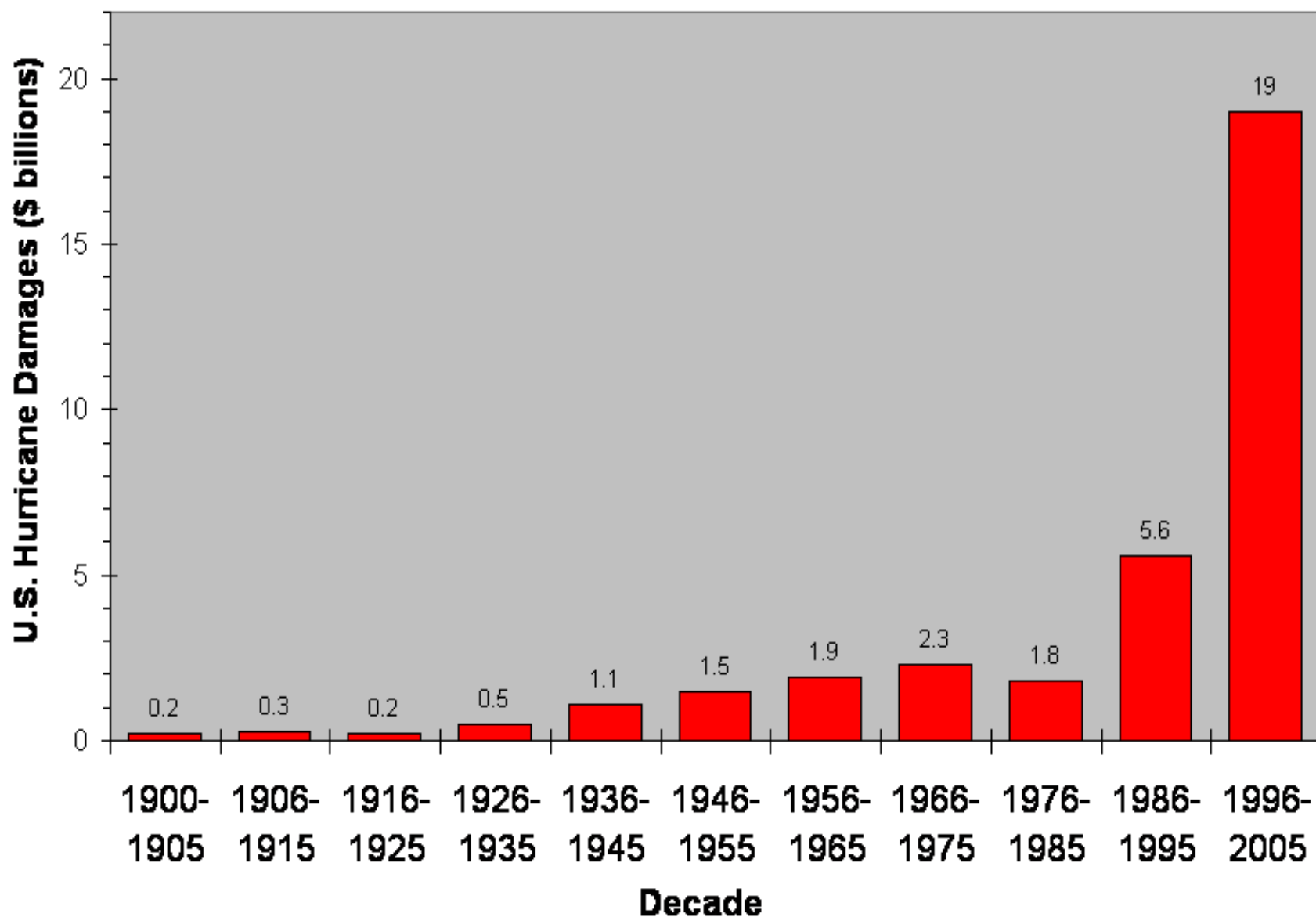
Wilma  
21 October

Emily  
17 July



# U.S. Tropical Storm and Hurricane Damages

## \$BILLIONS Annually - Inflation Adjusted





Increases in personal wealth (people have more “stuff”, and larger homes to stow their stuff, etc.) has led to greatly increased damage from hurricanes.

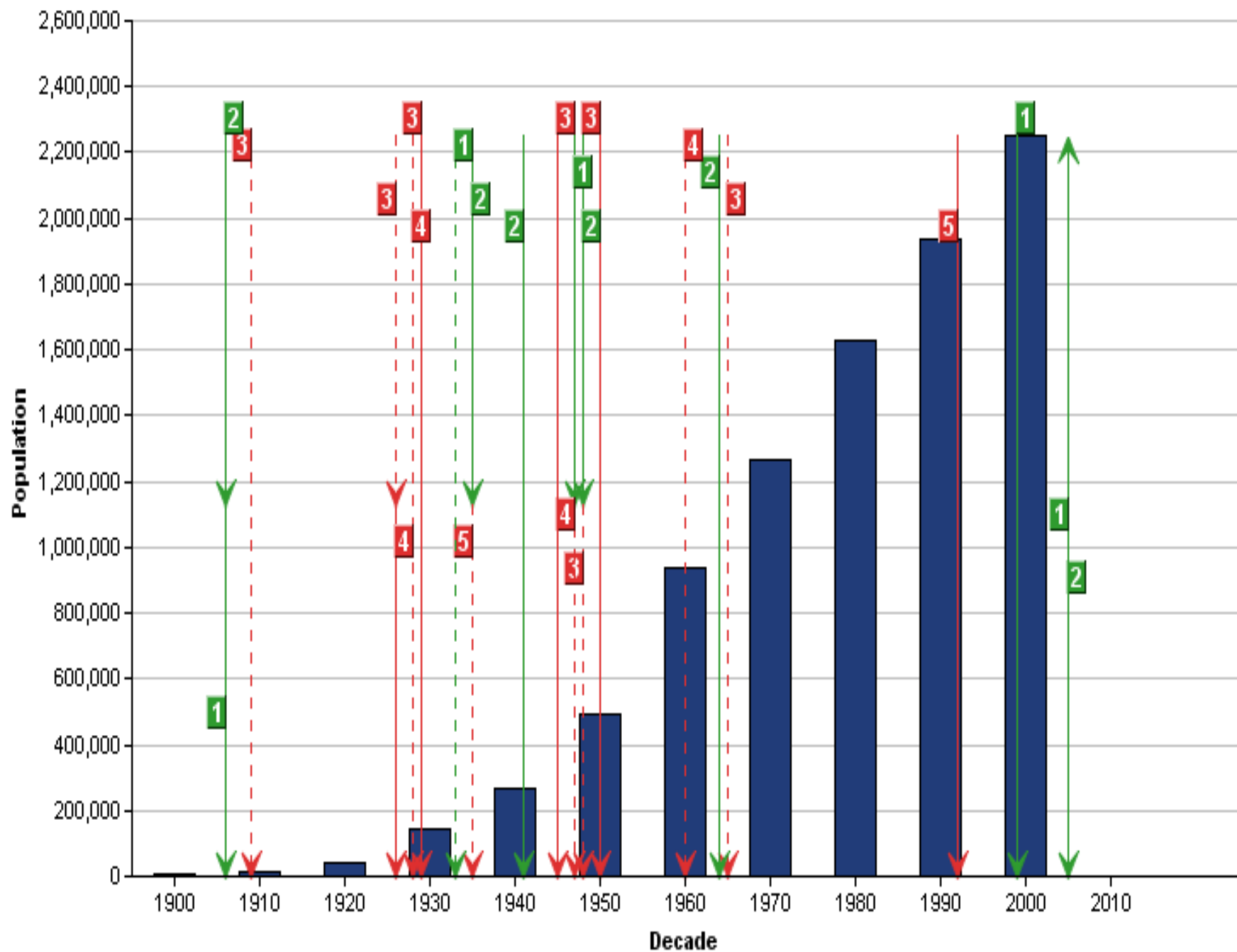








# Hurricane Strikes vs Population for Miami-Dade, Florida



# NORMALIZED DAMAGE...

Estimated direct damage if past storms made landfall with present-day societal conditions

$ND = f(\text{inflation, coastal population, wealth})$

Pielke and Landsea (1998)

$ND = f(\text{inflation, coastal housing, wealth})$

Pielke et al. (2008)



# 1926 Great Miami Hurricane

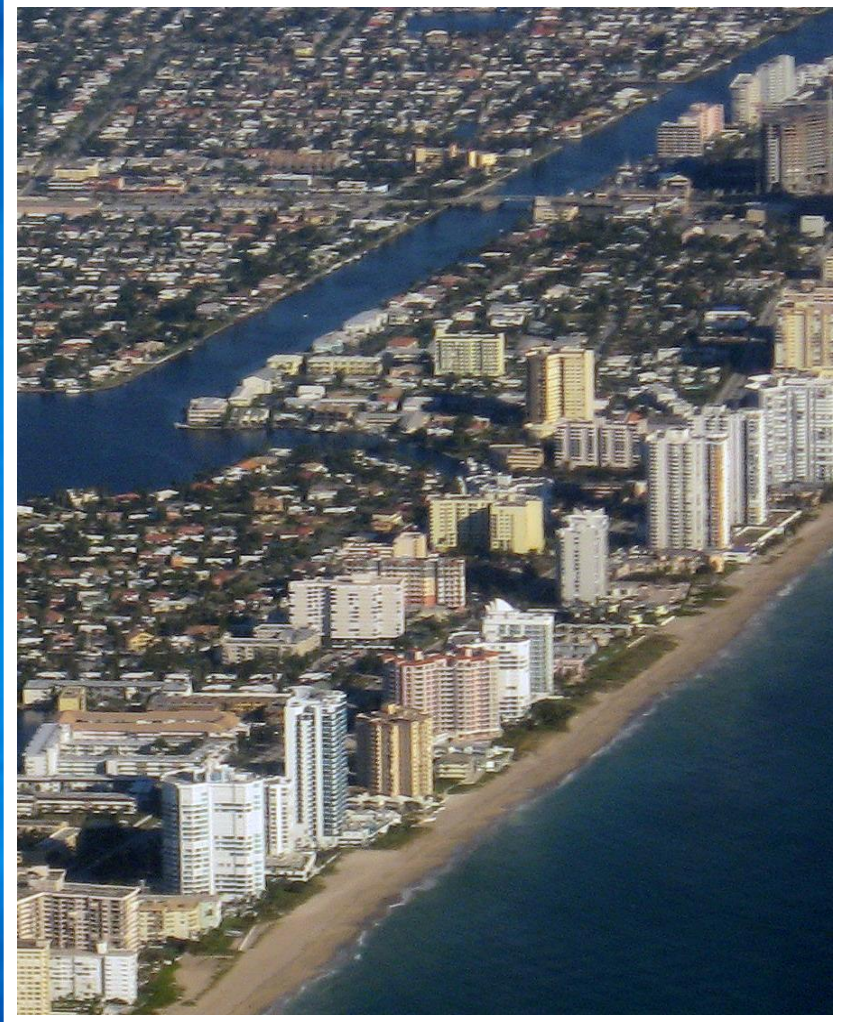
\$165 Billion Today

Miami Beach 1926



Wendler Collection

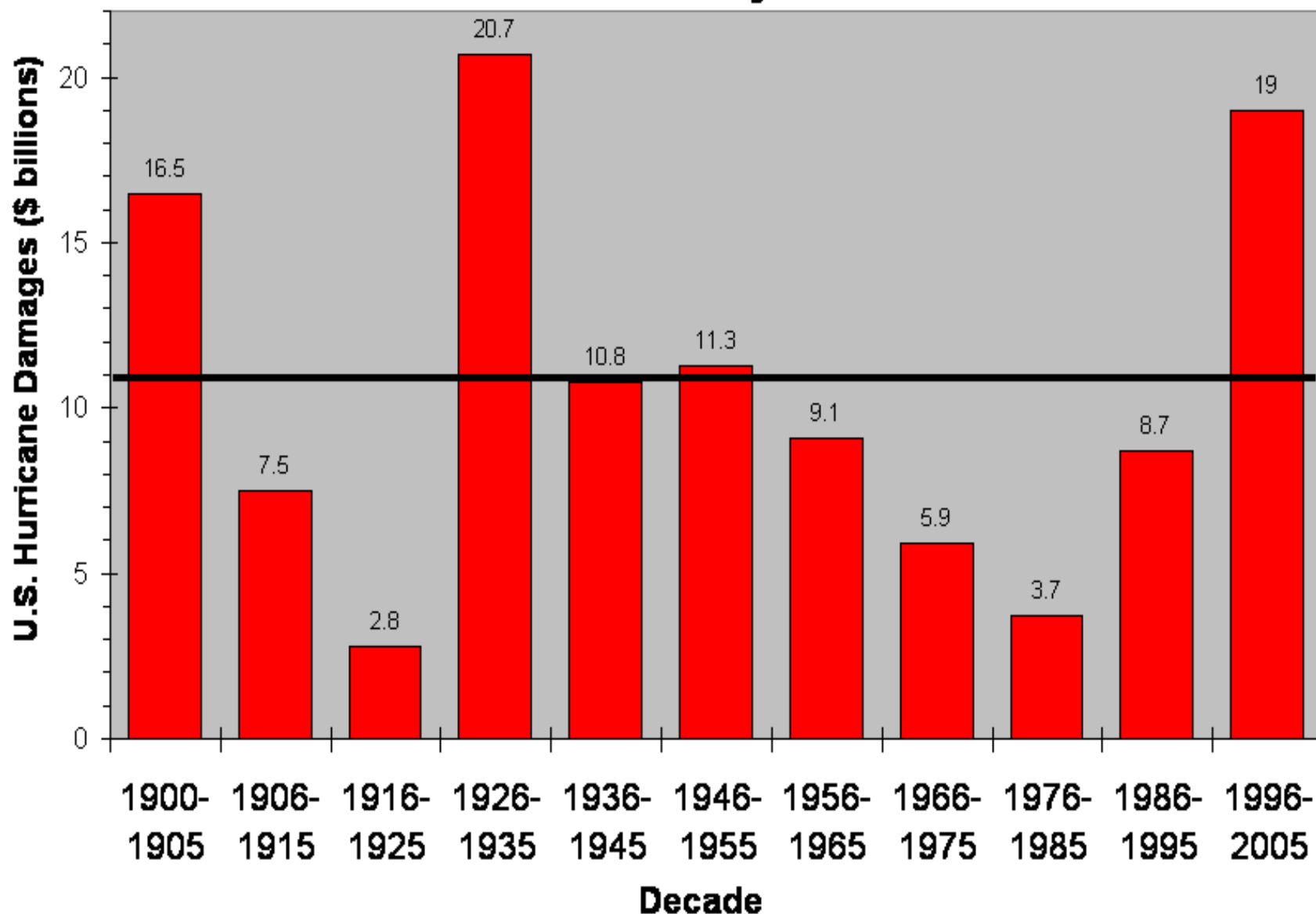
Miami Beach 2006



Joel Gratz © 2006

# U.S. Tropical Storm and Hurricane Damages

## \$BILLIONS Annually - Normalized





U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE  
NORTH ATLANTIC HURRICANE TRACKING CHART

2008

NUMBER	TYPE	NAME	DATE
1	T	ARTHUR	MAY 31-JUN 1
2	MH	BERTHA	JUL 3-20
3	T	CRISTOBAL	JUL 19-23
4	H	DOLLY	JUL 20-25
5	T	EDOUARD	AUG 3-6
6	T	FAY	AUG 15-26
7	MH	GUSTAV	AUG 25-SEP 4
8	H	HANNA	AUG 28-SEP 7
9	MH	IKE	SEP 1-14
10	T	JOSEPHINE	SEP 2-6
11	H	KYLE	SEP 25-29
12	T	LAURA	SEP 29-OCT 1
13	T	MARCO	OCT 6-7
14	T	NANA	OCT 12-14
15	MH	OMAR	OCT 13-18
16	MH	PALOMA	NOV 5-9

**What does the Atlantic hurricane database (HURDAT) show for changes in time of tropical storm and hurricane numbers?**

Major Hurricane  
Hurricane  
Tropical Storm  
Tropical Depression  
Subtropical Storm  
Subtropical Depression

“This record [of Atlantic tropical cyclone counts] ... shows a strong, long-term relationship with tropical Atlantic August-October SST...The underlying factor appears to be the influence of (primarily anthropogenic) forced large-scale warming.”

## Linking Atlantic storm numbers to ocean temperatures

Eos, Vol. 87, No. 24, 13 June 2006

# EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

## Atlantic Hurricane Trends Linked to Climate Change

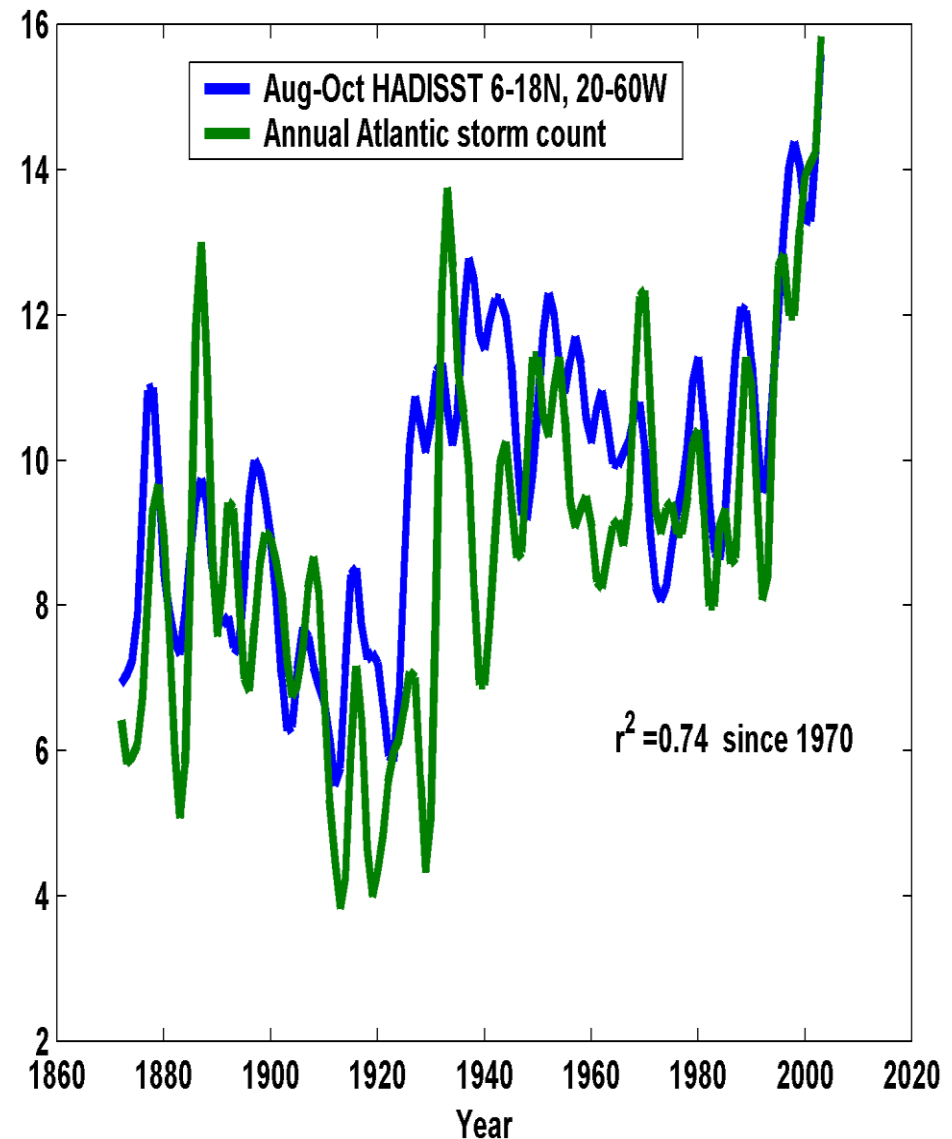
PAGES 233, 238, 241

Increases in key measures of Atlantic hurricane activity over recent decades are believed to reflect, in large part, contemporaneous increases in tropical Atlantic warmth [e.g., *Emanuel, 2005*]. Some recent studies [e.g., *Goldenberg et al., 2001*] have attributed these increases to a natural climate cycle

termed the Atlantic Multidecadal Oscillation (AMO), while other studies suggest that climate change may instead be playing the dominant role [Emanuel, 2005; Webster et al., 2005].

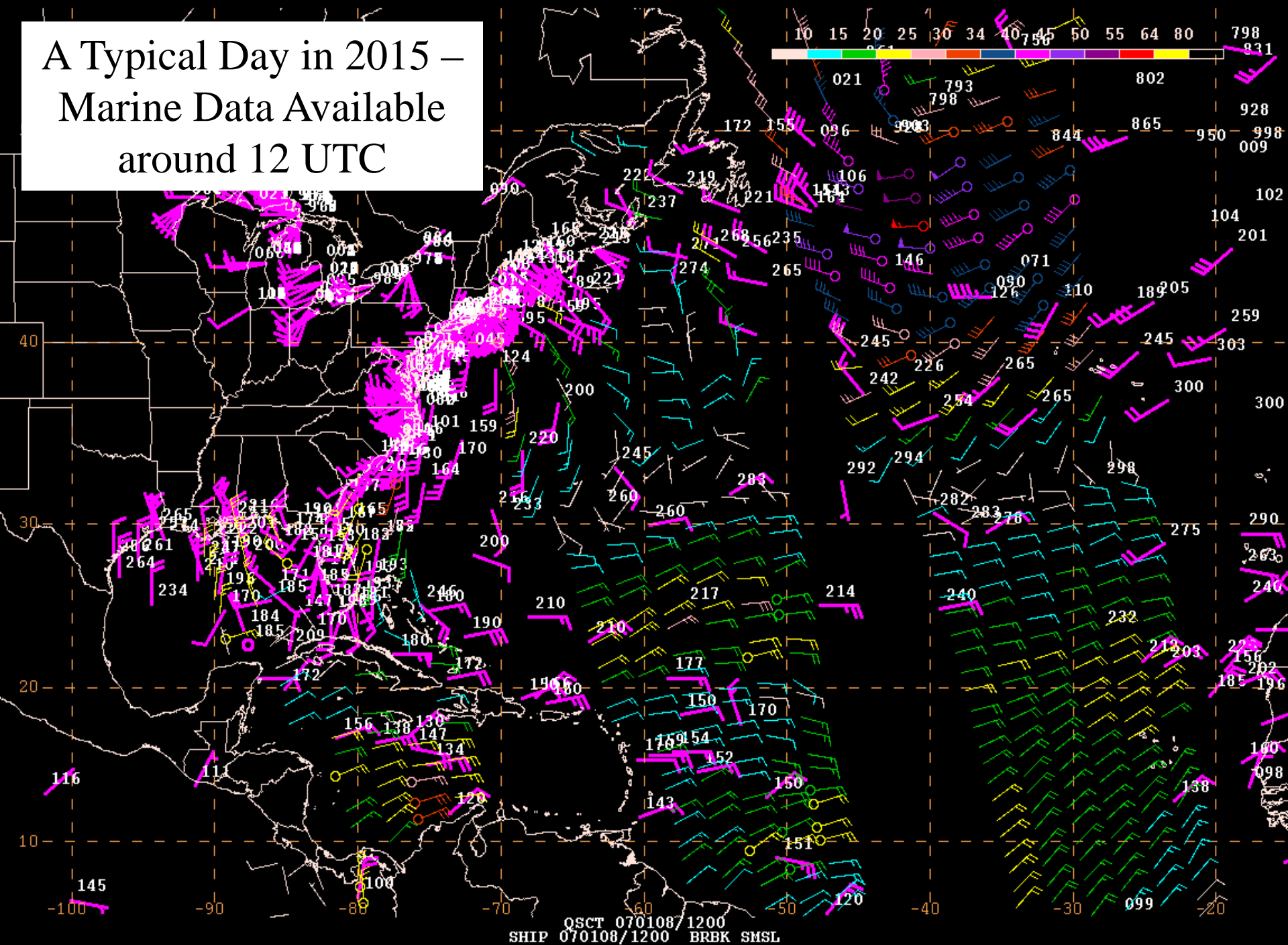
Using a formal statistical analysis to separate the estimated influences of anthropogenic climate change from possible natural cyclical influences, this article presents results indicating that anthropogenic factors are likely responsible for long-term trends in tropical Atlantic warmth and tropical cyclone

BY M. E. MANN AND K. A. EMANUEL





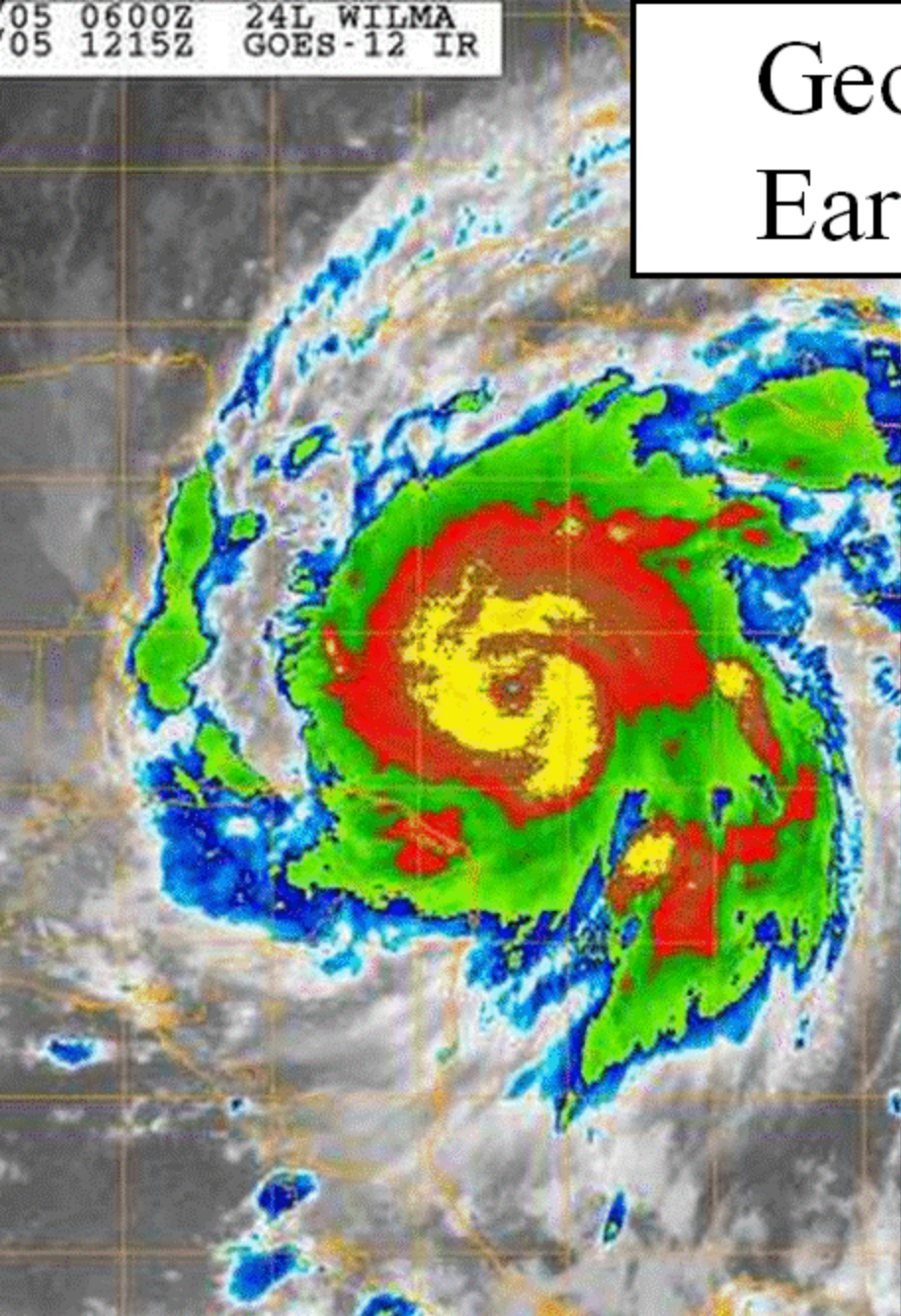
# A Typical Day in 2015 – Marine Data Available around 12 UTC





05 0600Z 24L WILMA  
05 1215Z GOES-12 IR

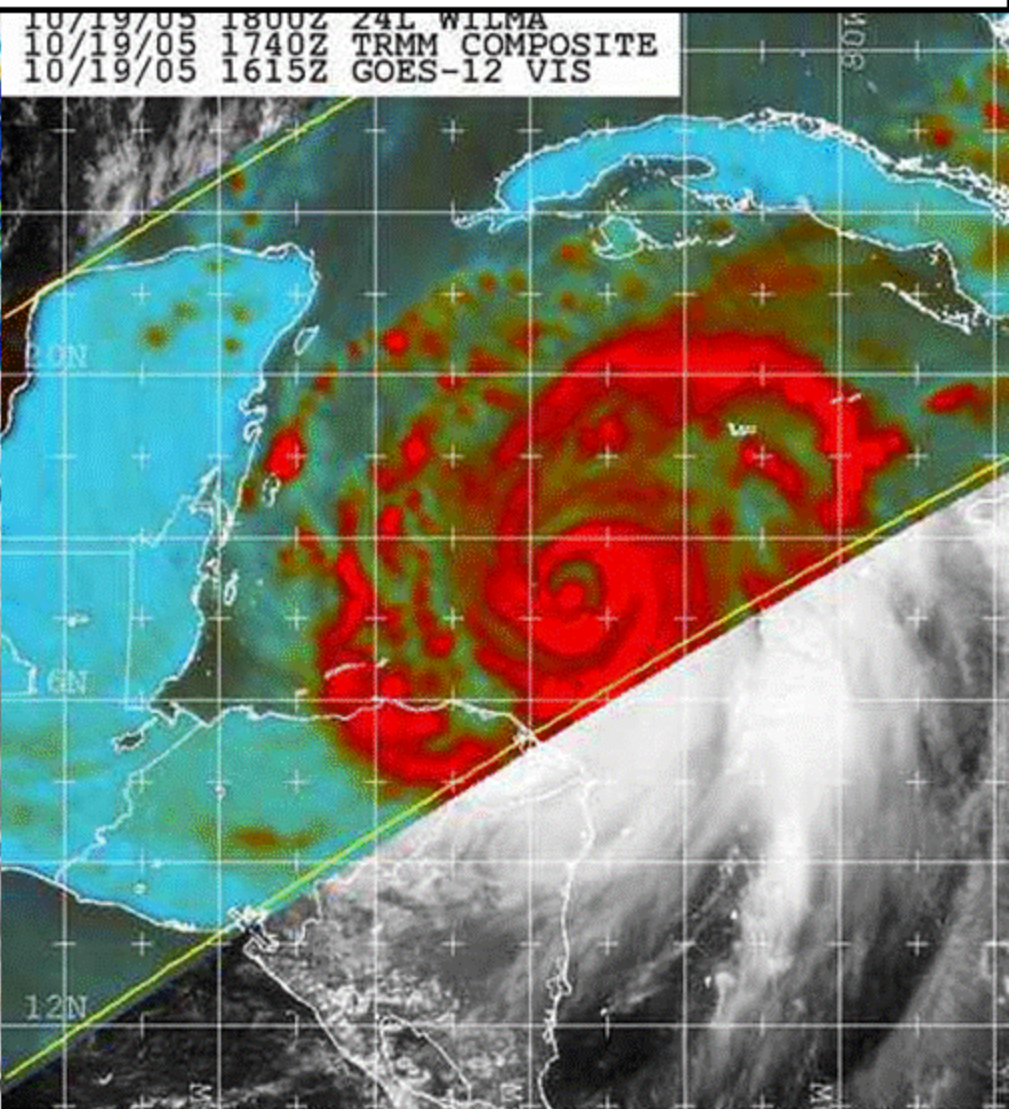
# Geostationary and Low-Earth Orbiting Satellites



Naval Research Lab [http://www.nrlmry.navy.mil/sat\\_products.htm](http://www.nrlmry.navy.mil/sat_products.htm)  
IR Temperature (Celsius)

-70 -60 -50 -40 -30 -20 -10

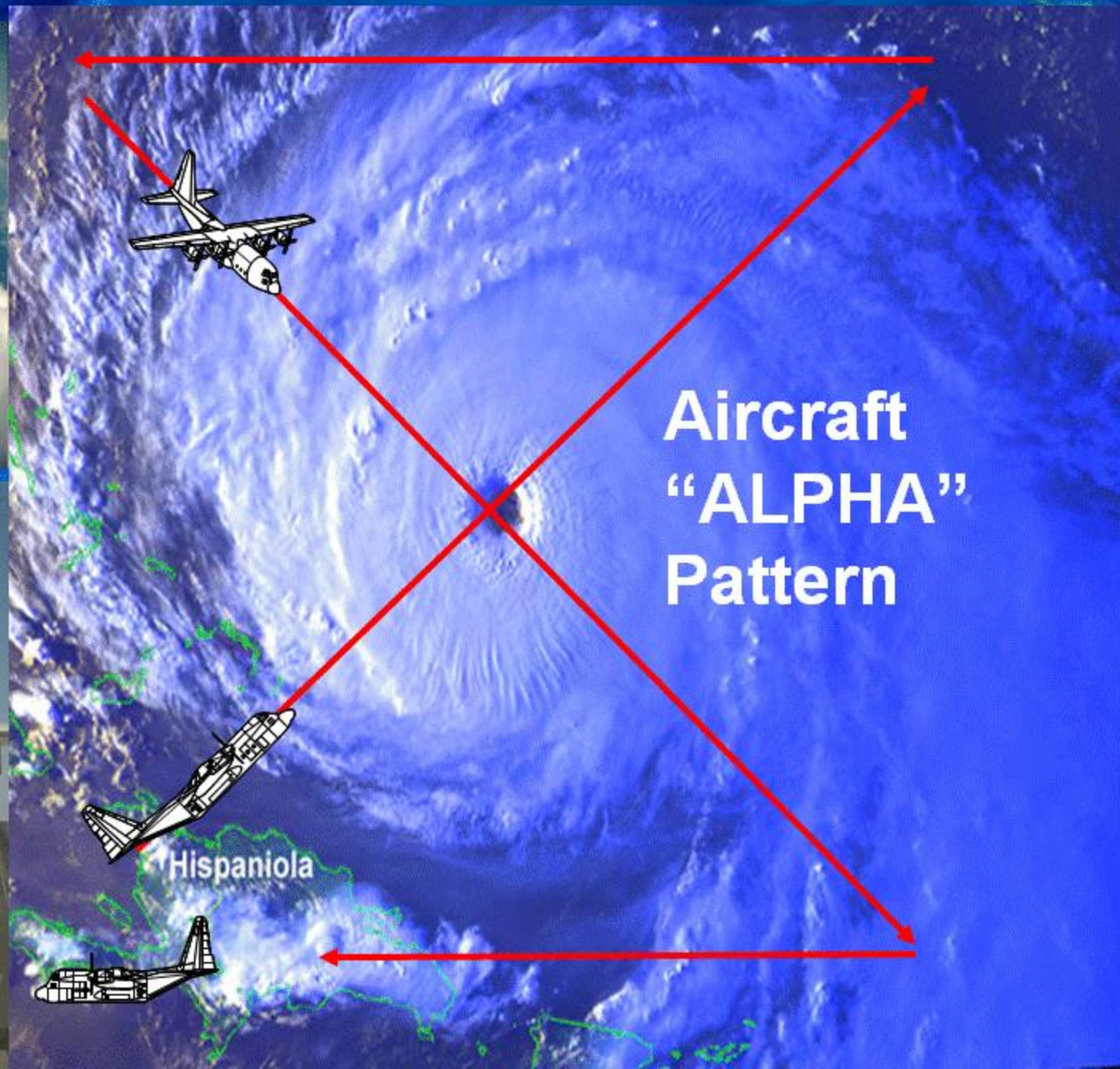
10/19/05 1800Z 24L WILMA  
10/19/05 1740Z TRMM COMPOSITE  
10/19/05 1615Z GOES-12 VIS



Naval Research Lab [www.nrlmry.navy.mil/sat\\_products.htm](http://www.nrlmry.navy.mil/sat_products.htm)  
Red=85PCT Green=85H Blue=85V



# RECONNAISSANCE FLIGHT PATH

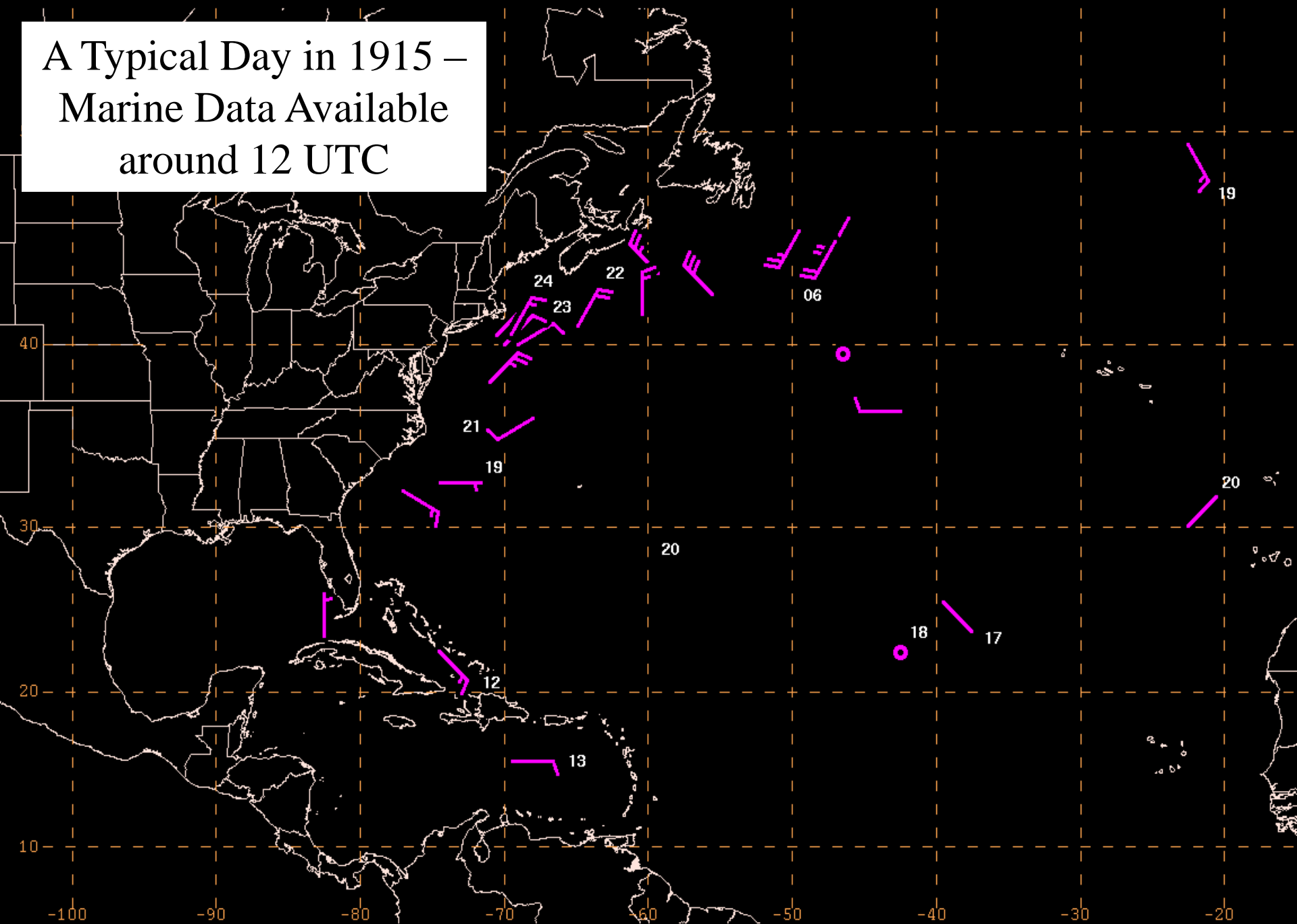








A Typical Day in 1915 –  
Marine Data Available  
around 12 UTC



A Typical Day in 1011

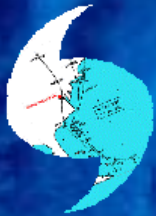


-100 -90 -80 -70 -60 -50 -40 -30 -20



# Atlantic Hurricane Database Re-Analysis Project

[http://www.aoml.noaa.gov/hrd/data\\_sub/re\\_anal.html](http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html)



1851 through 1955 changes accepted and officially adopted by NHC. Revisions for 1956 to 1963 have been submitted and are being considered. Remainder of 20<sup>th</sup> Century currently being reanalyzed.

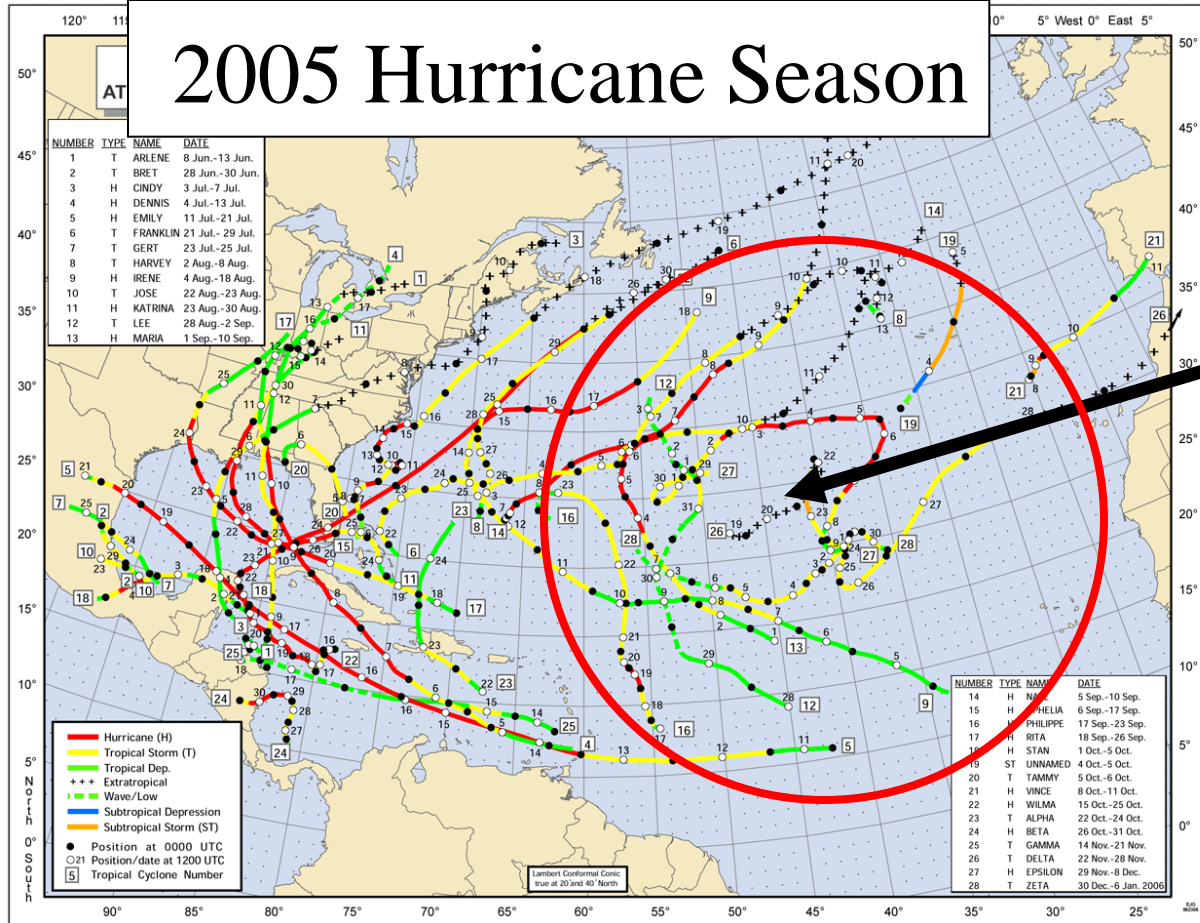


## RE-ANALYSES NEED TO BE CONDUCTED GLOBALLY!!!

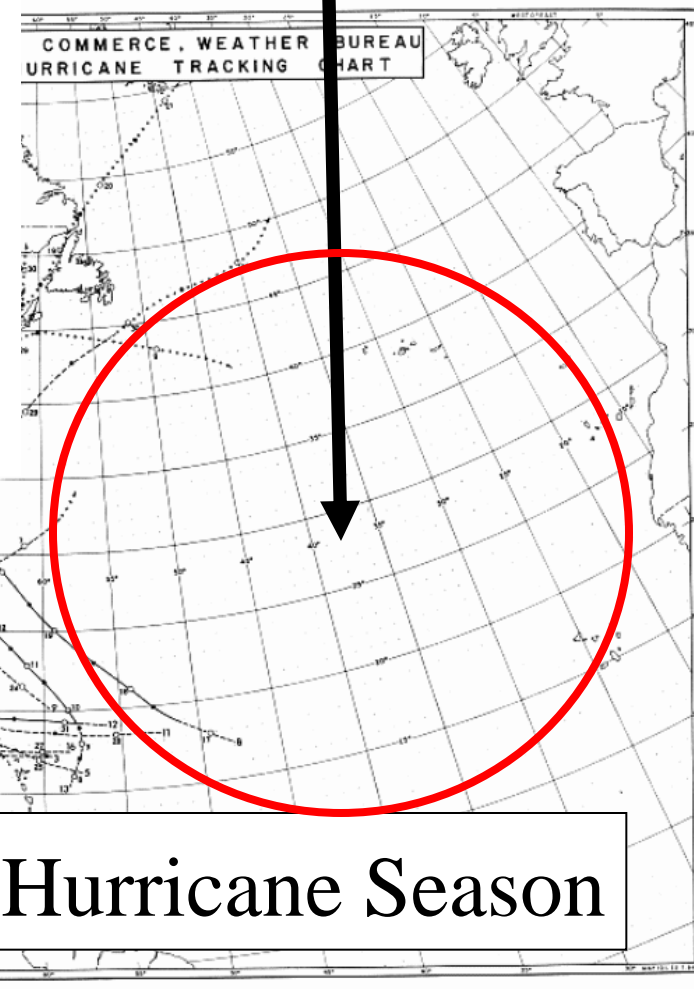




# 2005 Hurricane Season



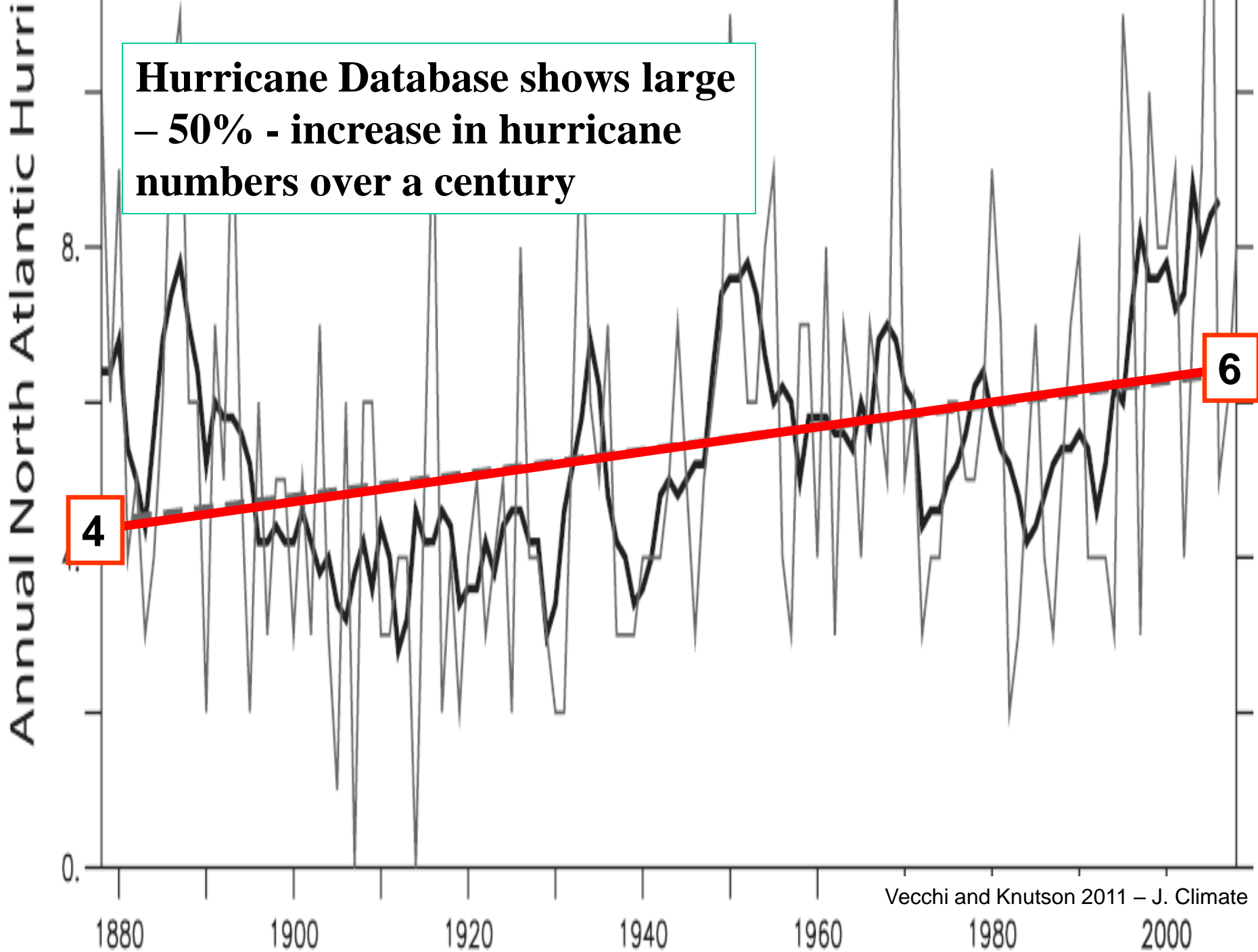
Open Atlantic  
Ocean Differences



# 1933 Hurricane Season

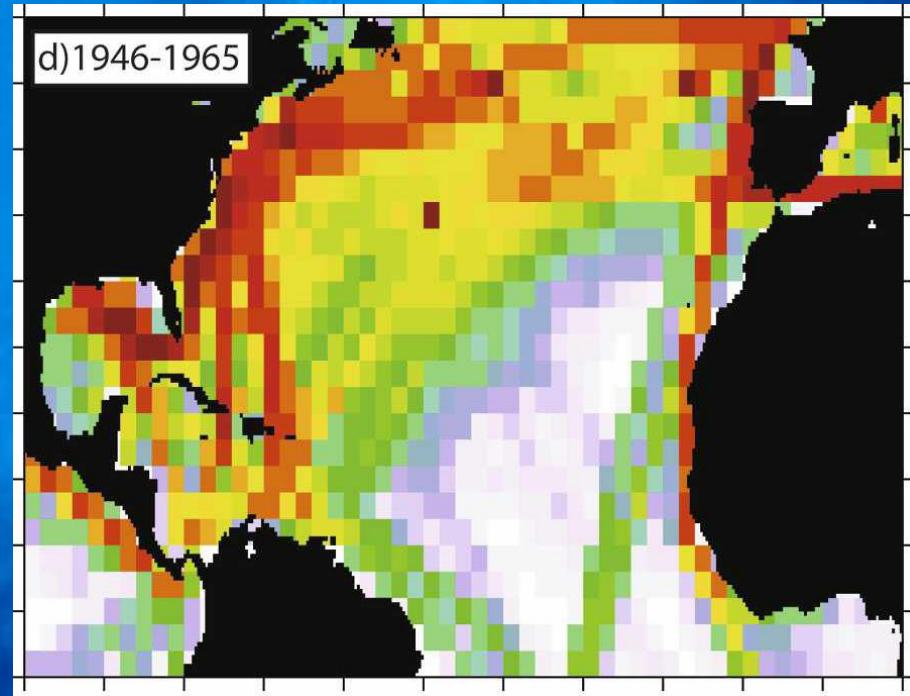
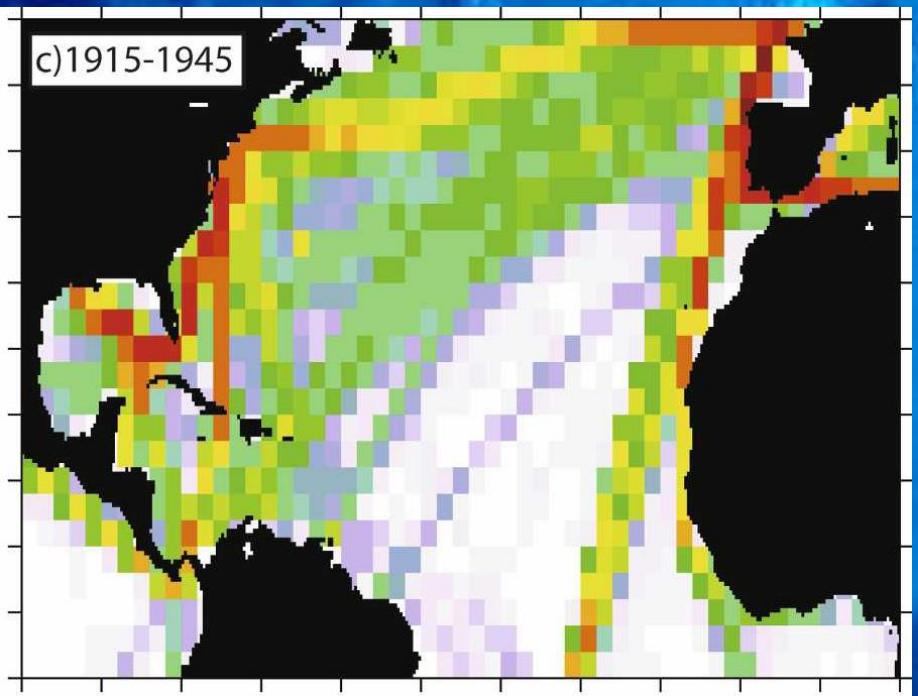
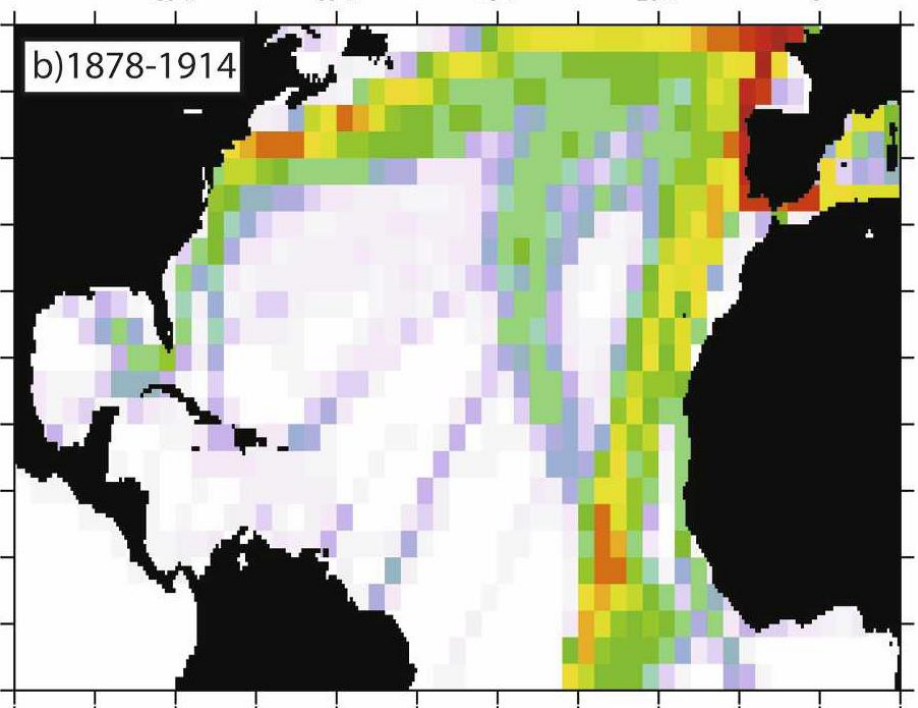


**Hurricane Database shows large  
– 50% - increase in hurricane  
numbers over a century**

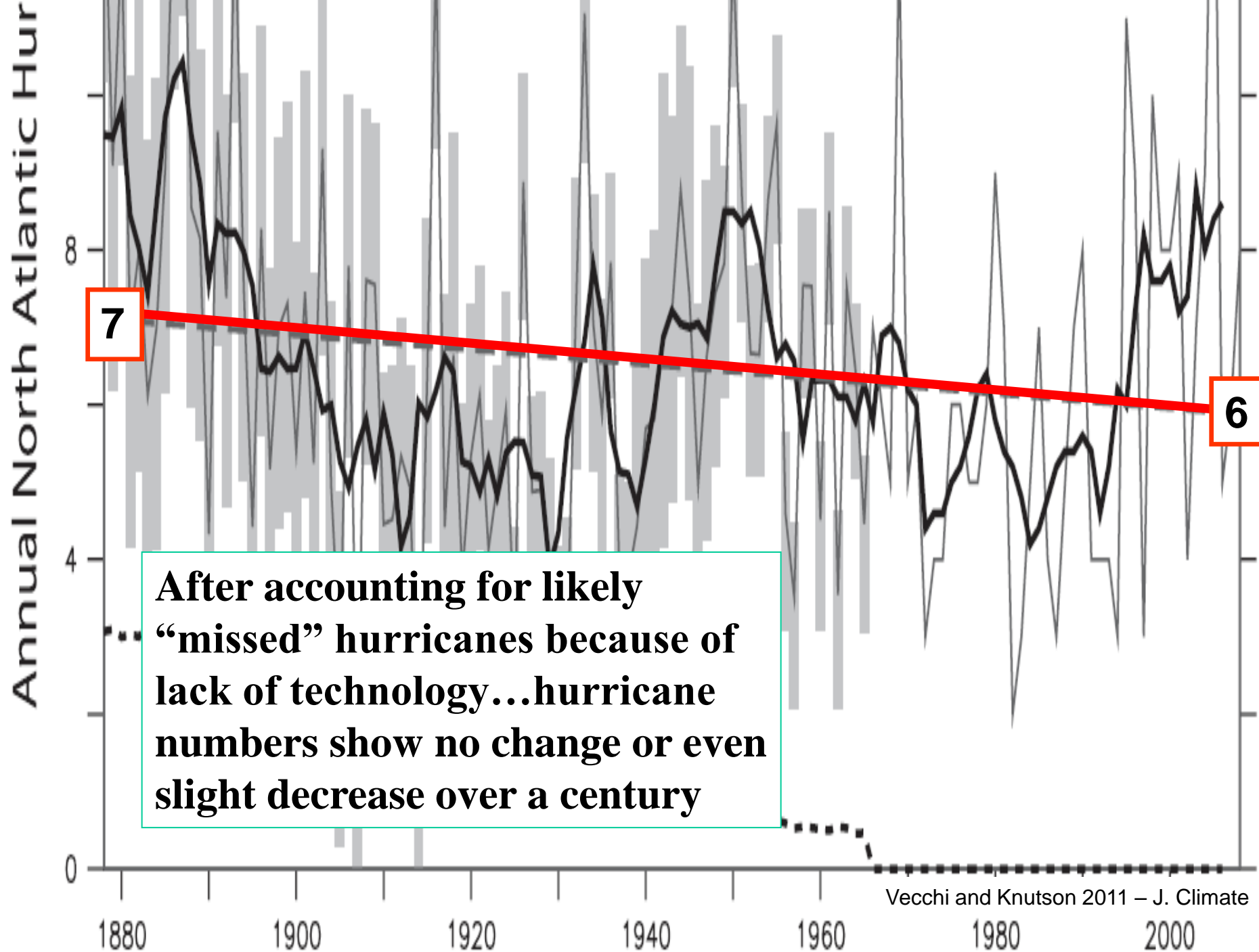


# Atlantic ship traffic changes

Vecchi and Knutson (2008)

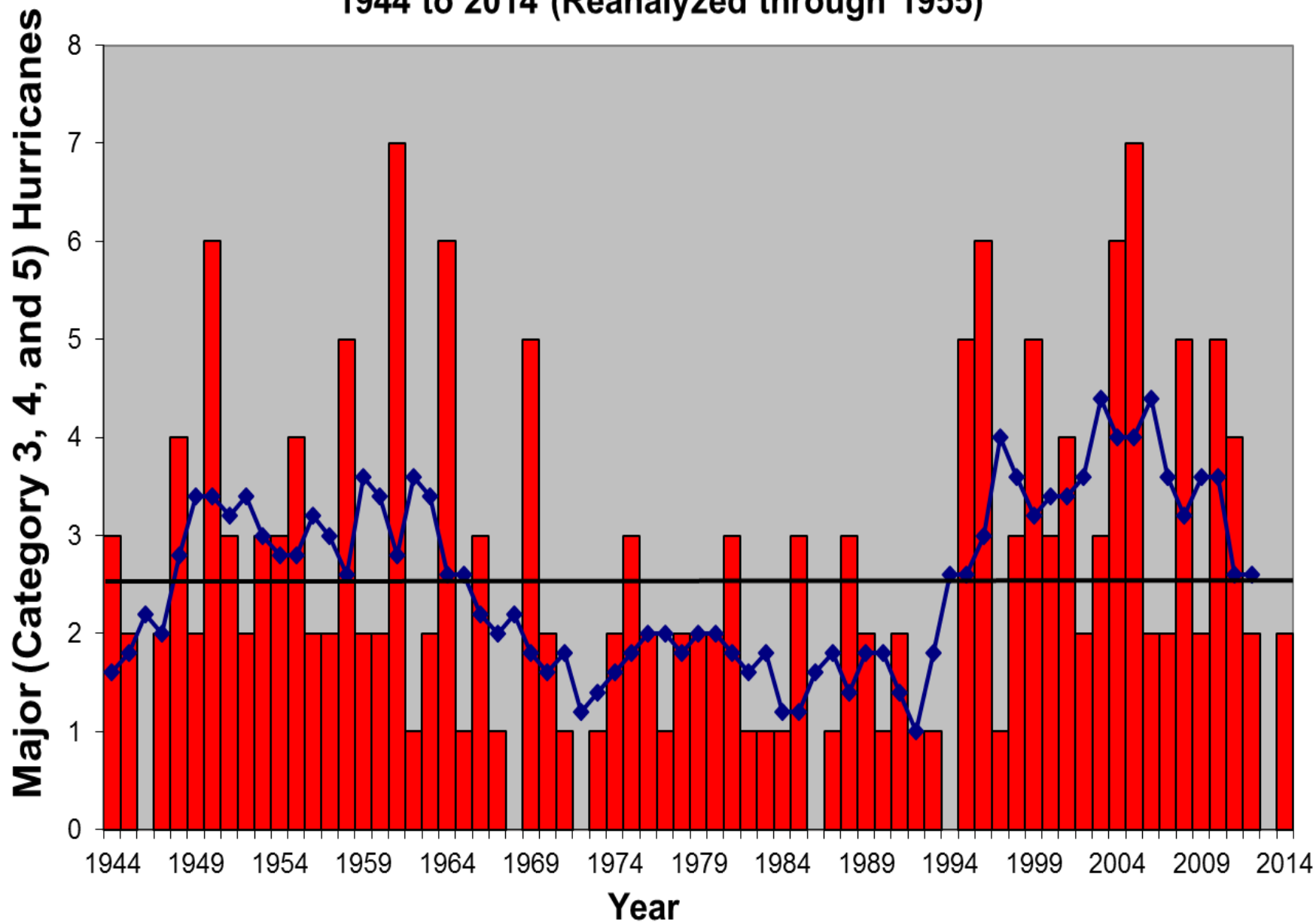






# Atlantic Basin Major Hurricanes

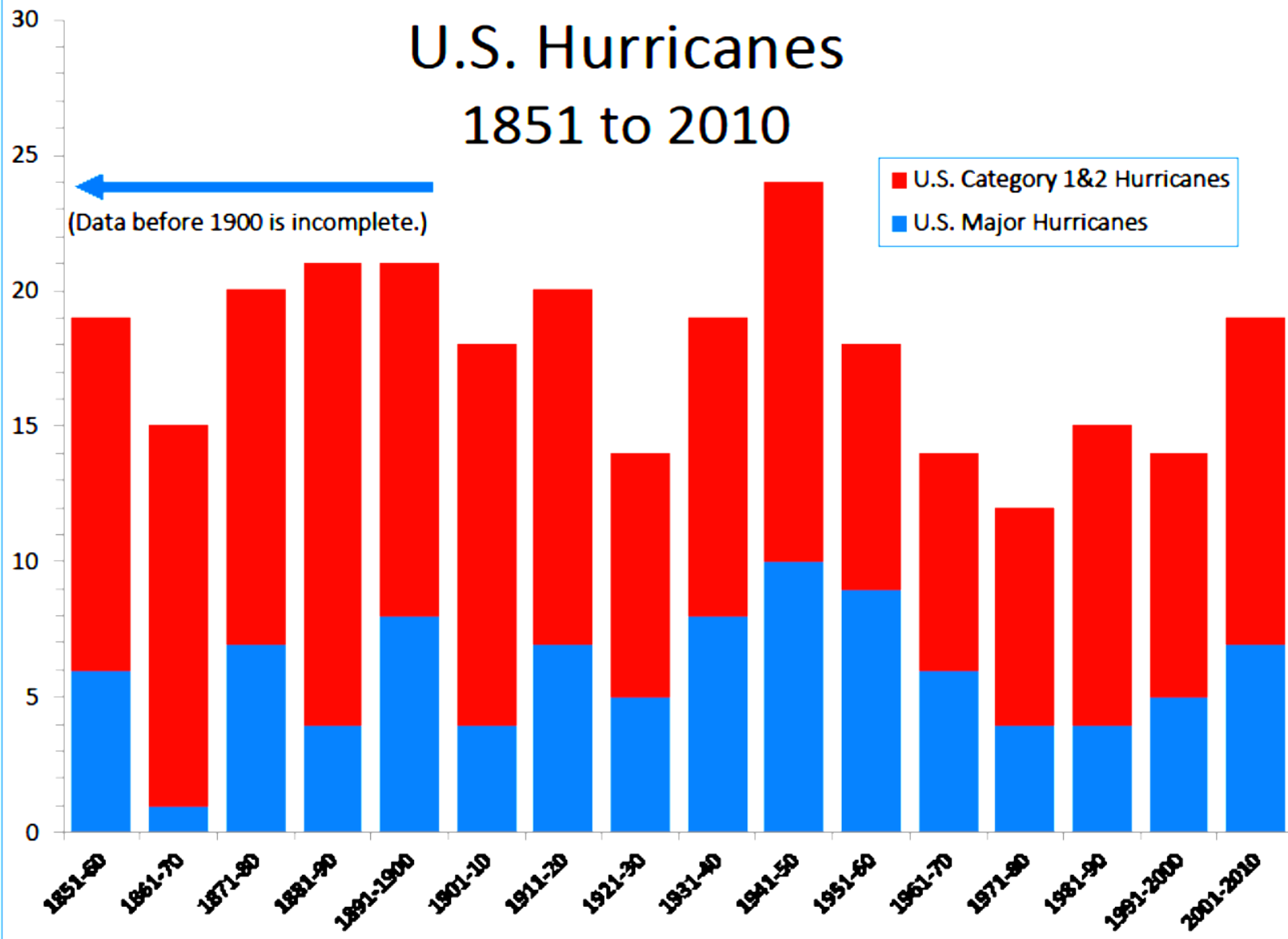
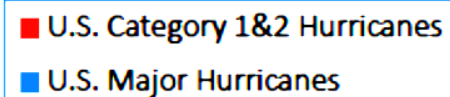
1944 to 2014 (Reanalyzed through 1955)





# U.S. Hurricanes 1851 to 2010

(Data before 1900 is incomplete.)



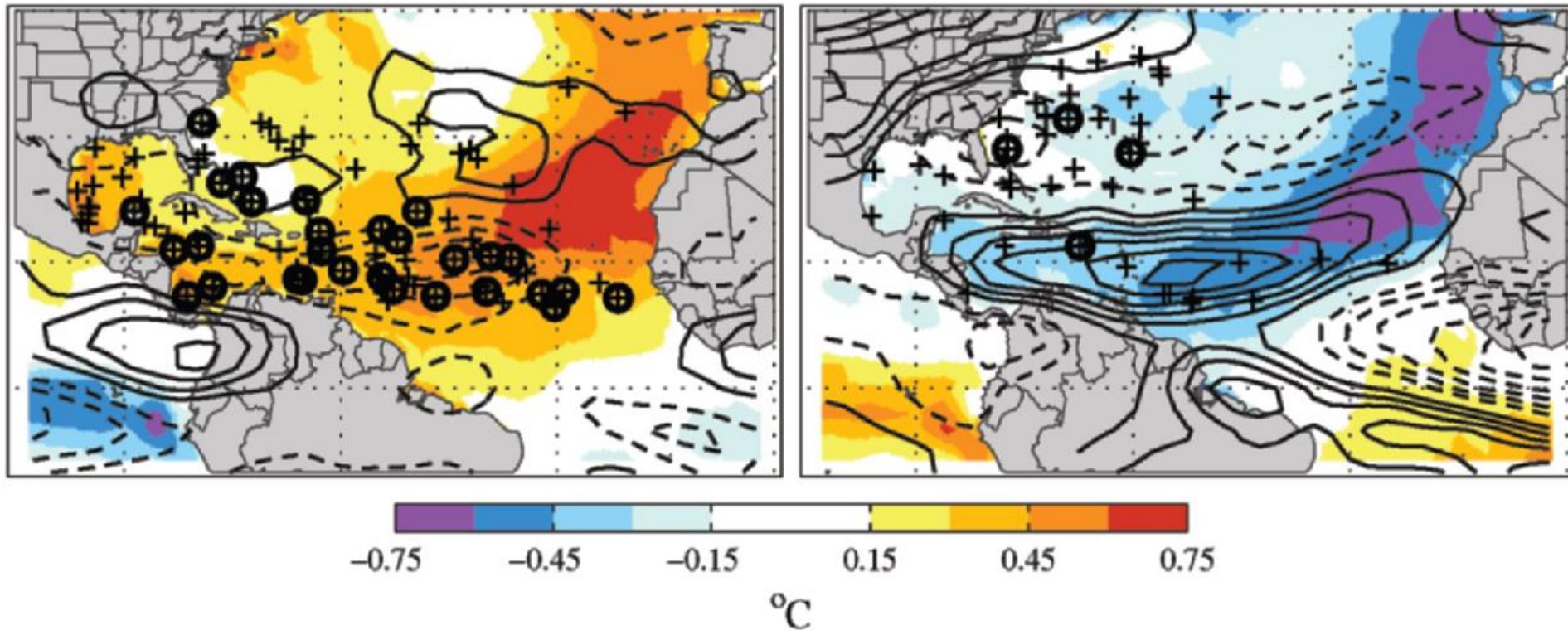
# Atlantic Multidecadal Oscillation

- SSTs, Vertical Shear and Cyclogenesis

## Composites around AMM

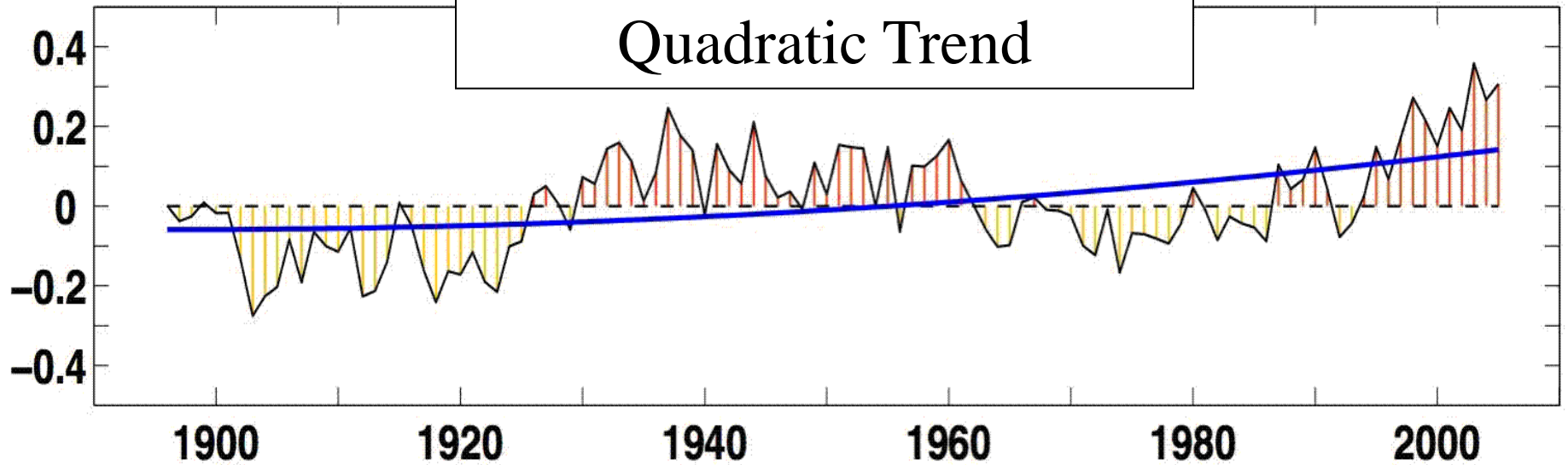
AMM(+)

AMM(-)

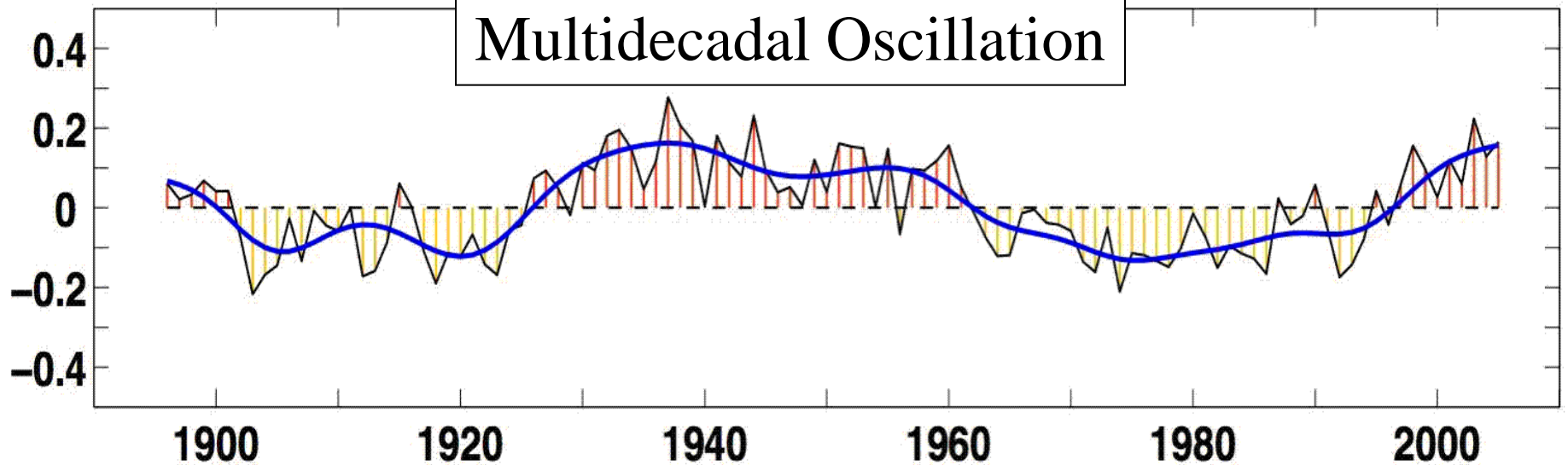




## North Atlantic SSTs and Quadratic Trend



## Residual Atlantic Multidecadal Oscillation

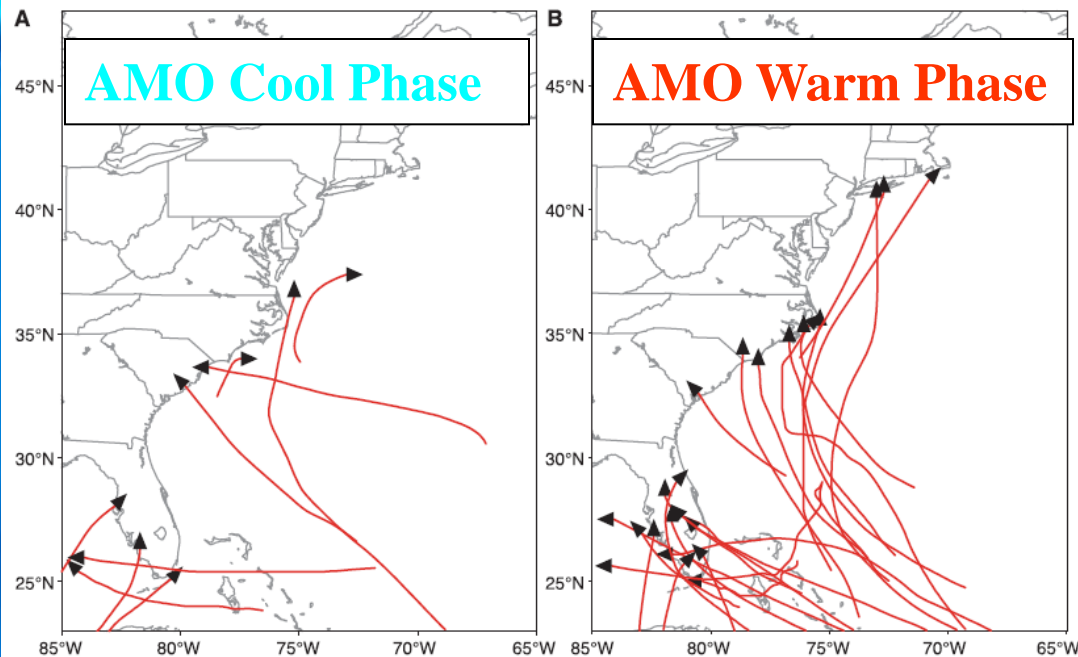


# The Recent Increase in Atlantic Hurricane Activity: Causes and Implications

Stanley B. Goldenberg,<sup>1\*</sup> Christopher W. Landsea,<sup>1</sup>  
Alberto M. Mestas-Nuñez,<sup>2</sup> William M. Gray<sup>3</sup>

The years 1995 to 2000 experienced the highest level of North Atlantic hurricane activity in the reliable record. Compared with the generally low activity of the previous 24 years (1971 to 1994), the past 6 years have seen a doubling of overall activity for the whole basin, a 2.5-fold increase in major hurricanes ( $\geq 50$  meters per second), and a fivefold increase in hurricanes affecting the Caribbean. The greater activity results from simultaneous increases in North Atlantic sea-surface temperatures and decreases in vertical wind shear. Because these changes exhibit a multidecadal time scale, the present high level of hurricane activity is likely to persist for an additional  $\sim 10$  to 40 years. The shift in climate calls for a reevaluation of preparedness and mitigation strategies.

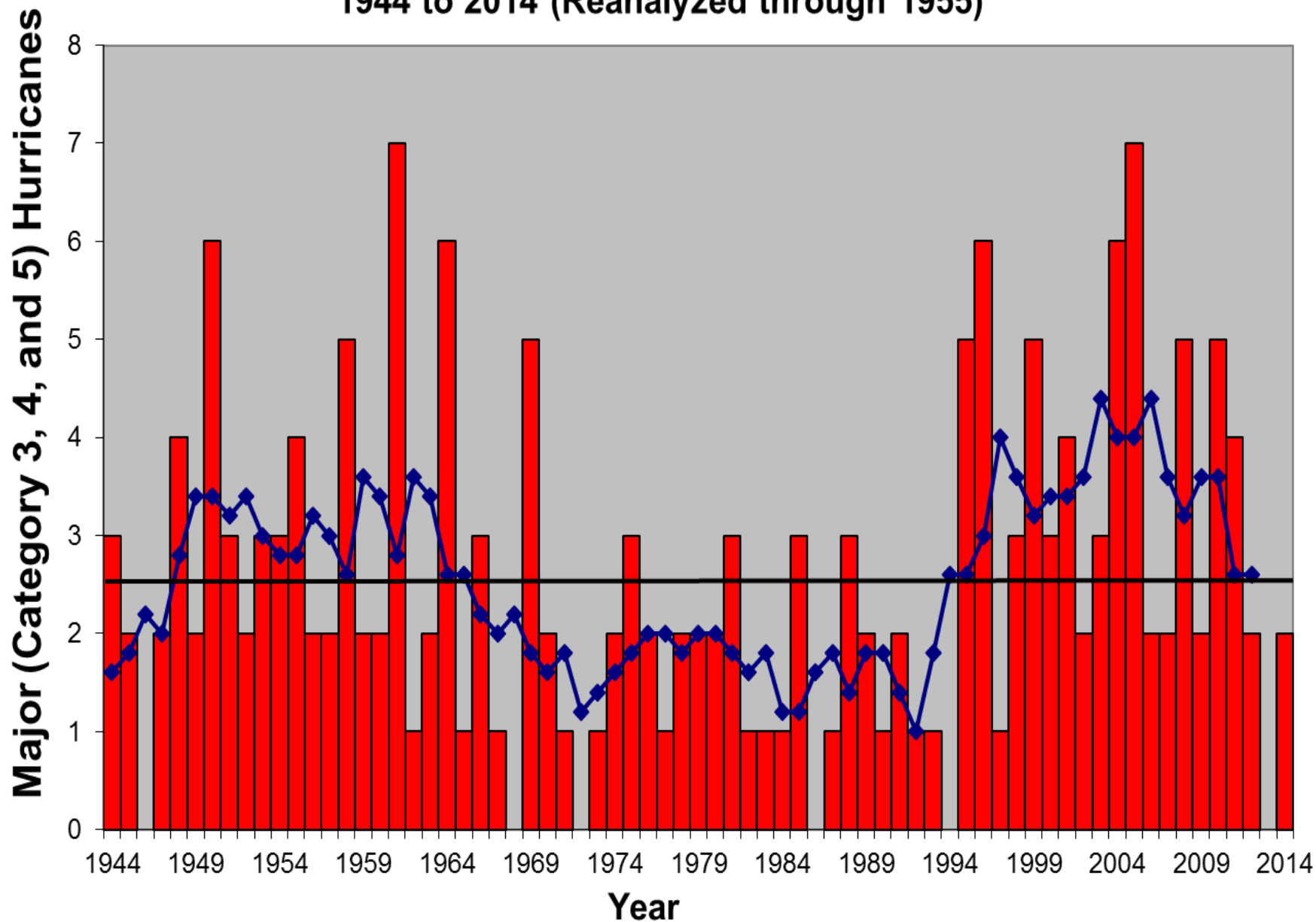
20 JULY 2001 VOL 293 SCIENCE



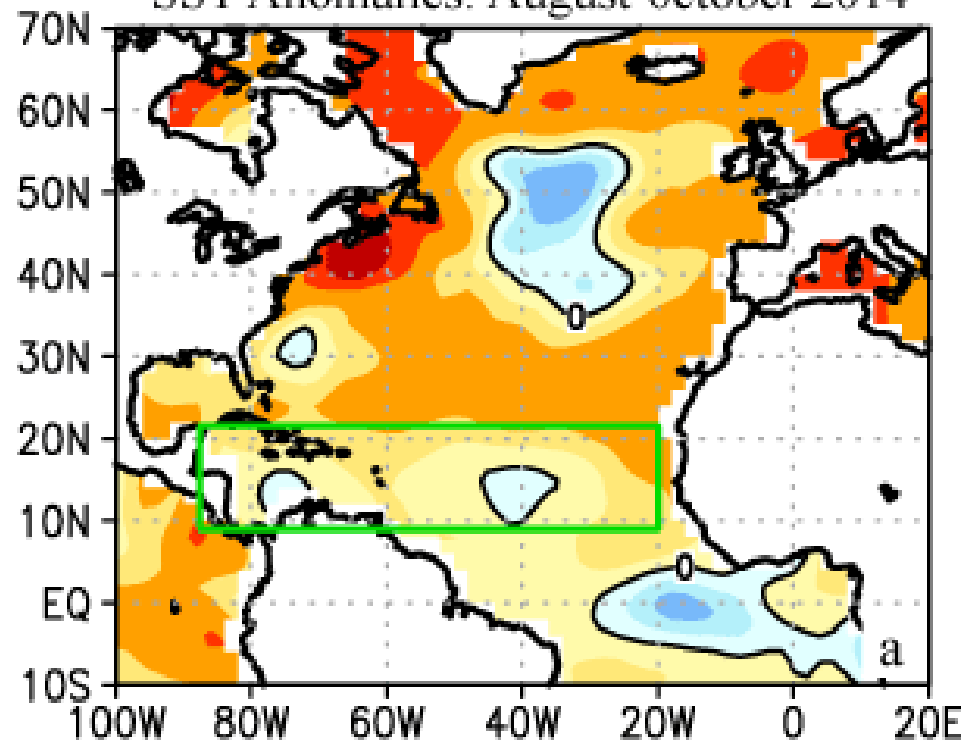


# Atlantic Basin Major Hurricanes

1944 to 2014 (Reanalyzed through 1955)



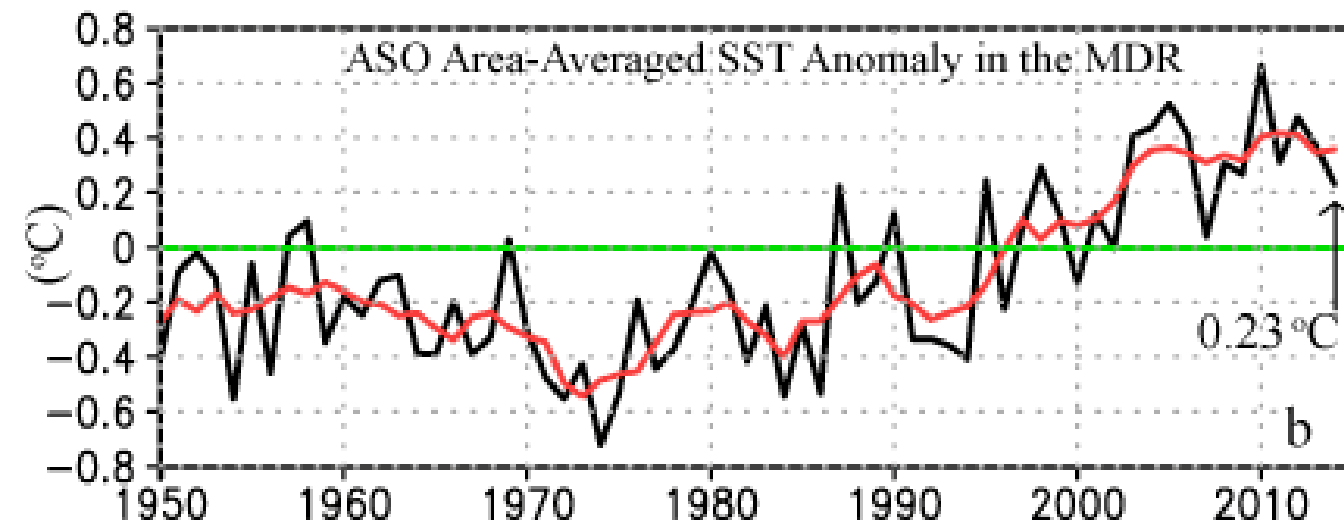
SST Anomalies: August-October 2014



Warm  
Atlantic  
Phase  
Remains  
Thus Far...

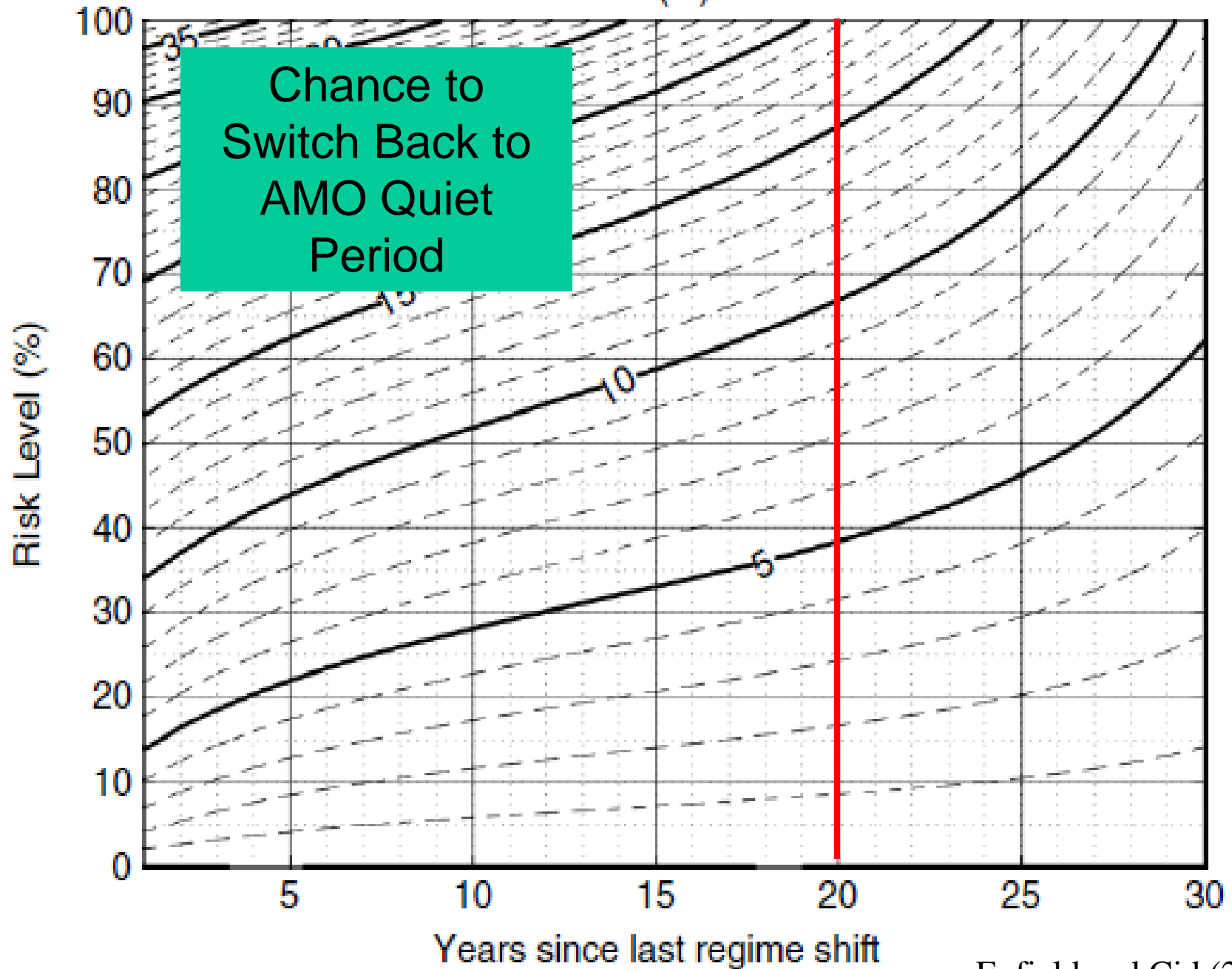
Expectation  
for Active  
Hurricane  
Seasons  
Overall to  
Continue

ASO Area-Averaged SST Anomaly in the MDR

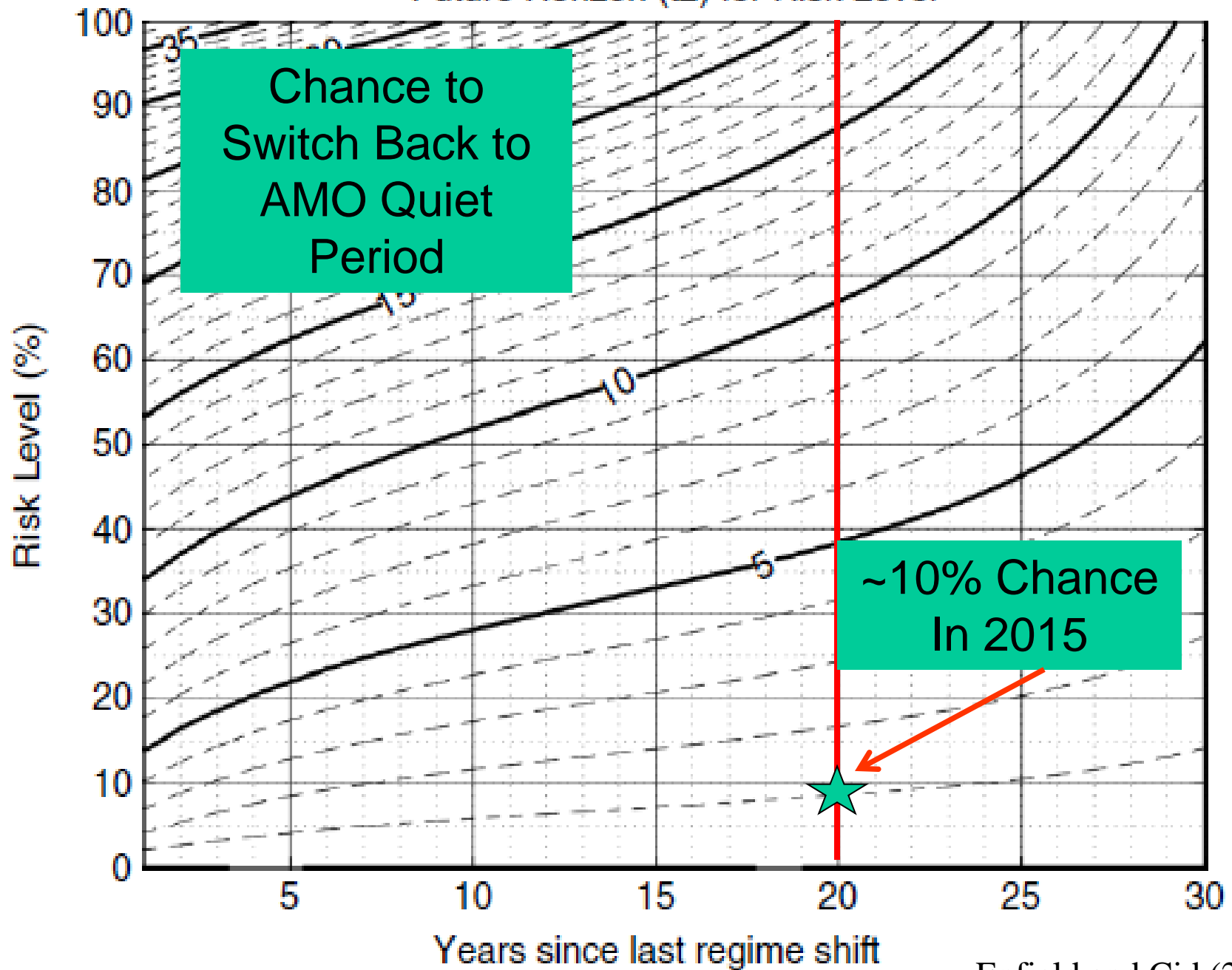




# Future Horizon (t2) for Risk Level

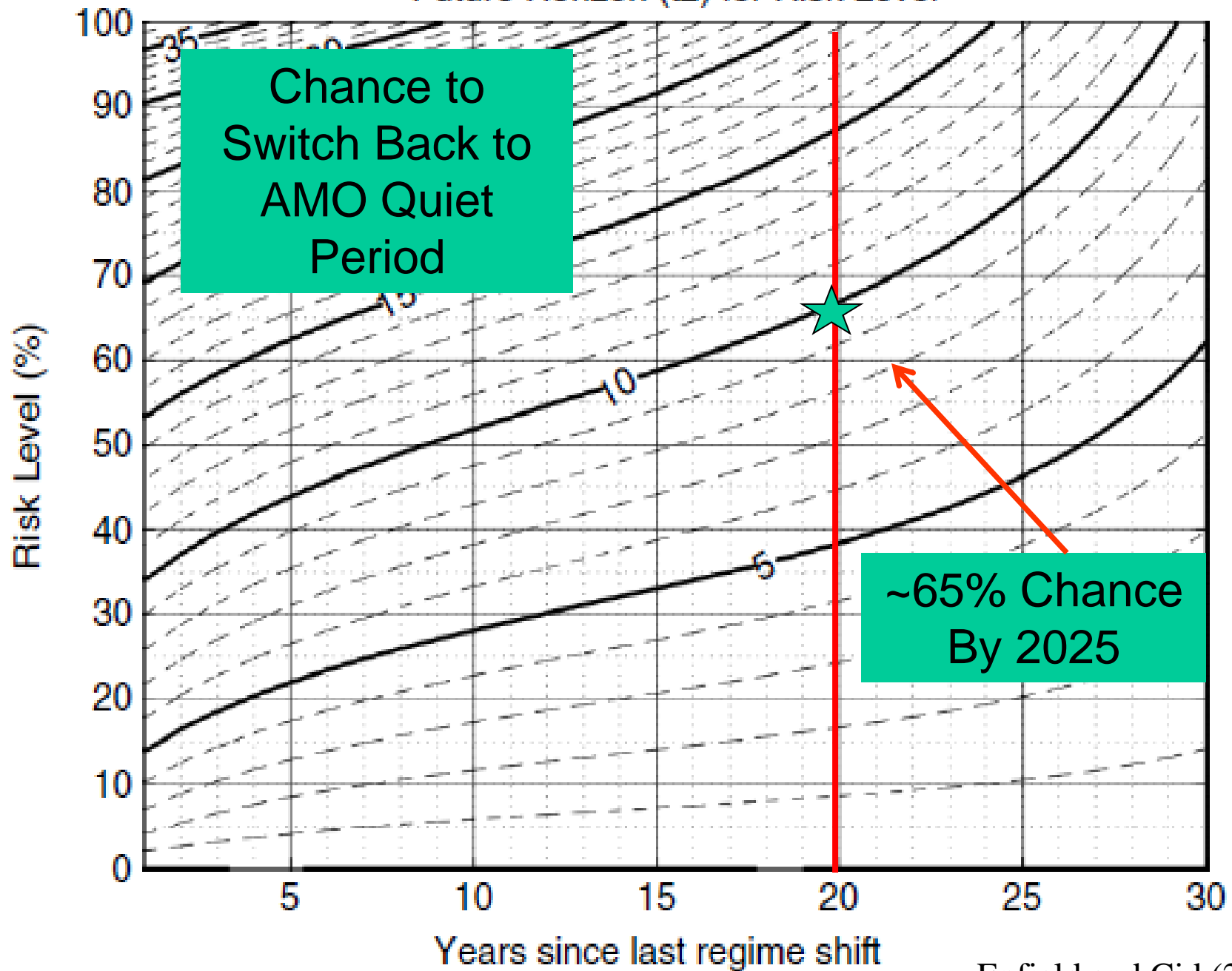


## Future Horizon (t2) for Risk Level





## Future Horizon (t2) for Risk Level



# Overall Tropical Storm and Hurricane Changes Due to Global Warming by 2100

**Frequency:** Numbers may see a **moderate decrease** (~25%)

**Wind Intensity:** **Small increase** (~3% stronger)

**Storm Surge:** **Small increase** (~3% higher) produced by the hurricane (must also add on additional amount from general sea level rise)

**Rainfall:** **Moderate increase** per tropical storm and hurricane (~10% within 200 mi of storm), but reduced frequency may offset increases

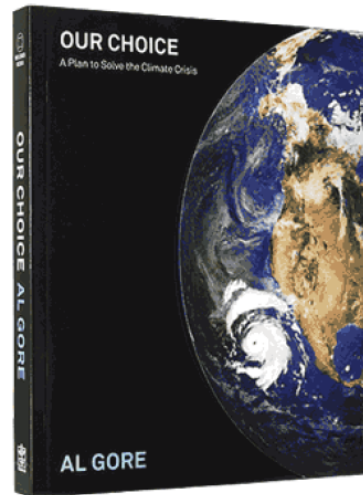
**Genesis:** Tropical storms and hurricanes to form **slightly farther away** from North America

**Track:** Tropical storms and hurricanes to **recurve slightly more often over water** and remain away from land



# Hurricanes and Global Warming

Opinion piece by Christopher W. Landsea  
November 2011



## Hurricanes as the Poster-Child for Global Warming

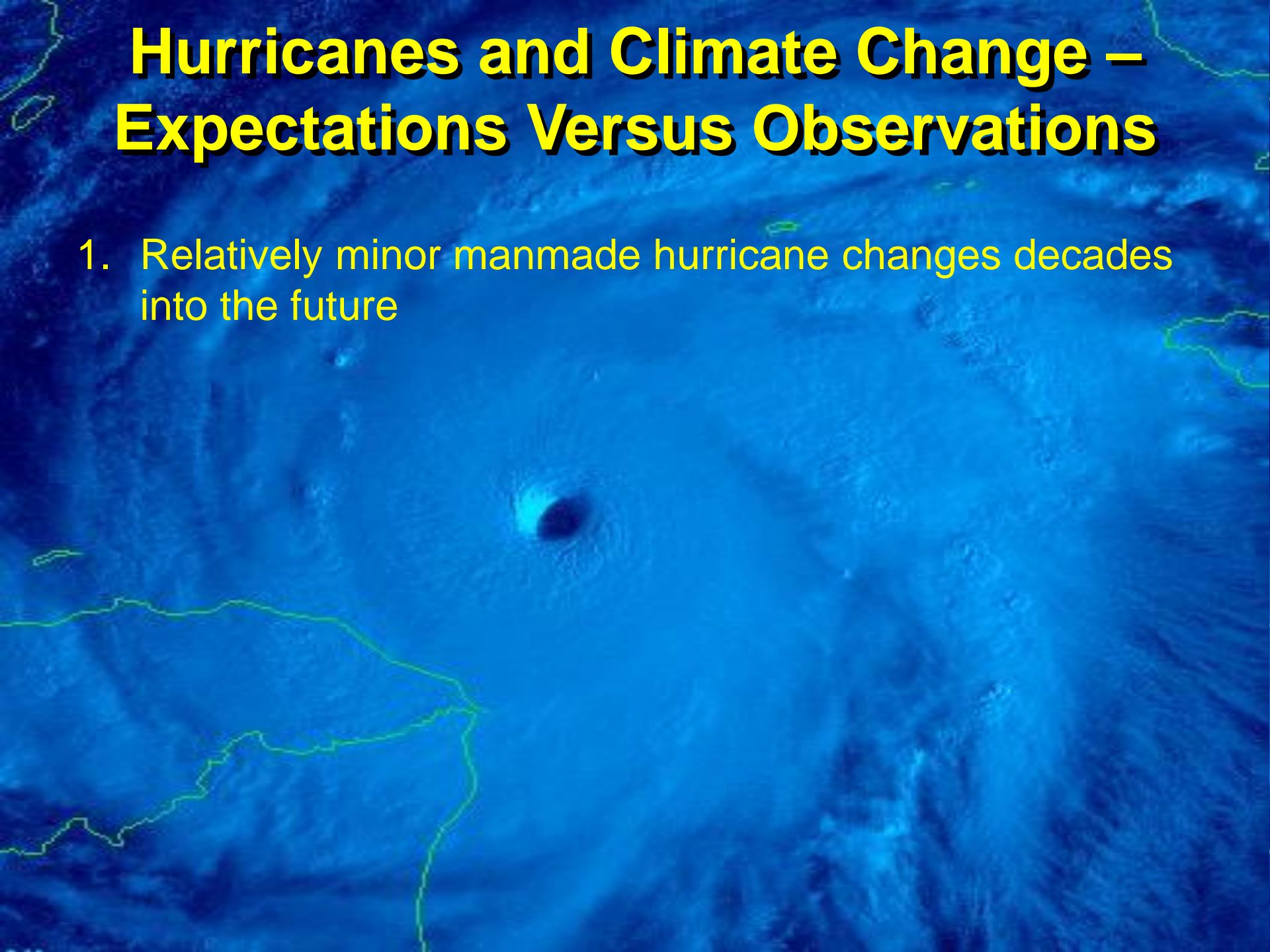
Hurricanes have been depicted as the literal poster-child of the harmful impacts of global warming. Without argument, hurricanes (which also include storms known as "typhoons" in the Northwest Pacific and "severe tropical cyclones" in the Indian and Southwest Pacific) are extremely destructive and often responsible for the deaths of hundreds and occasionally thousands of people. As an example, Hurricane Katrina was responsible for the death of ~1200 and about \$108 billion in damages.<sup>2</sup> The before and after pictures of the home of David and Kimberly King of Waveland, Mississippi show the incredible power of that hurricane's storm surge and winds.

Opinion Piece on  
Hurricanes and  
Global Warming

[http://www.aoml.noaa.gov/hrd/Landsea/gw\\_hurricanes/index.html](http://www.aoml.noaa.gov/hrd/Landsea/gw_hurricanes/index.html)

# Hurricanes and Climate Change – Expectations Versus Observations

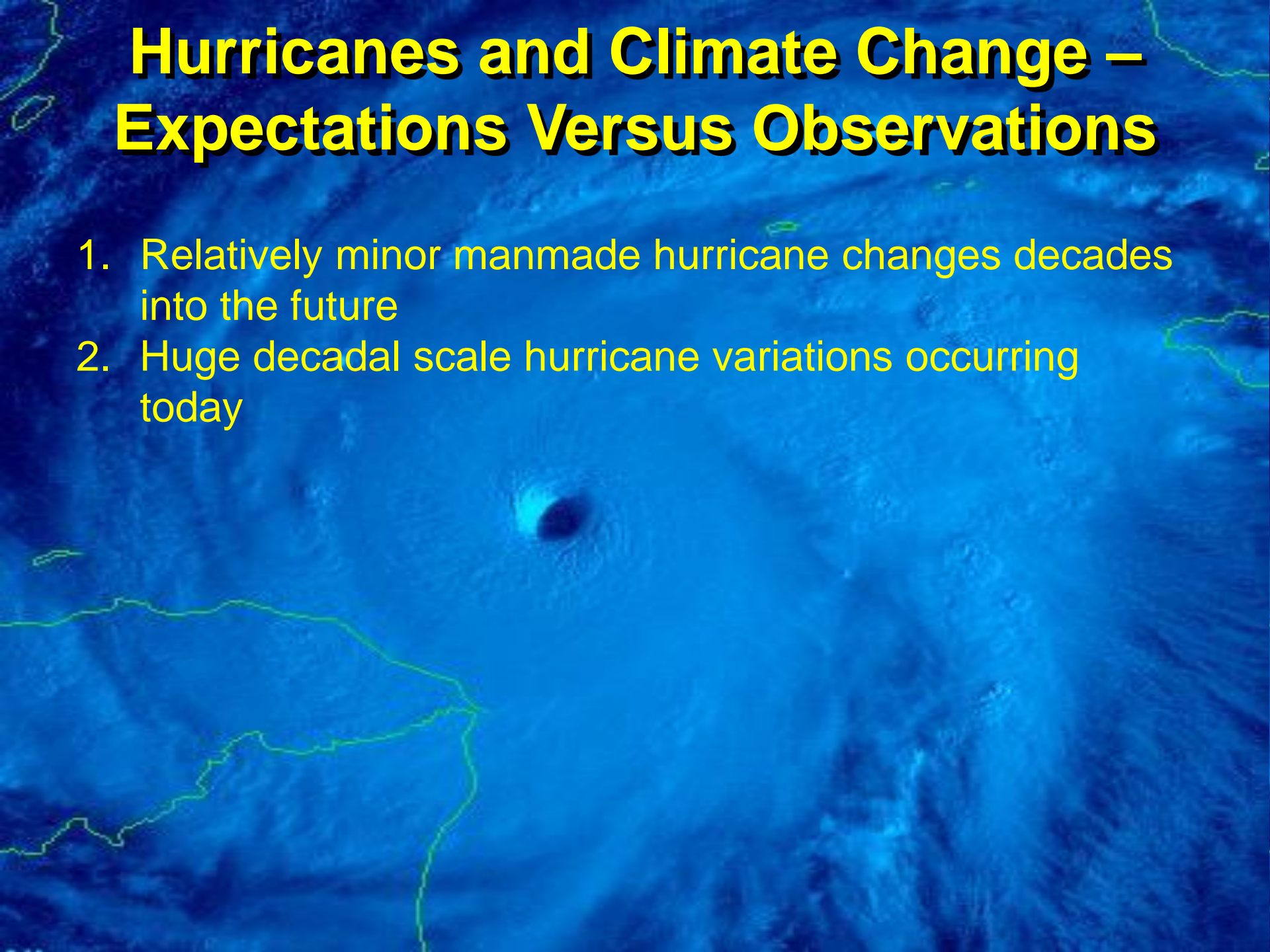
1. Relatively minor manmade hurricane changes decades into the future





# Hurricanes and Climate Change – Expectations Versus Observations

1. Relatively minor manmade hurricane changes decades into the future
2. Huge decadal scale hurricane variations occurring today



# Hurricanes and Climate Change – Expectations Versus Observations

1. Relatively minor manmade hurricane changes decades into the future
2. Huge decadal scale hurricane variations occurring today
3. Huge vulnerability issues today, which will get increasingly severe as population grows



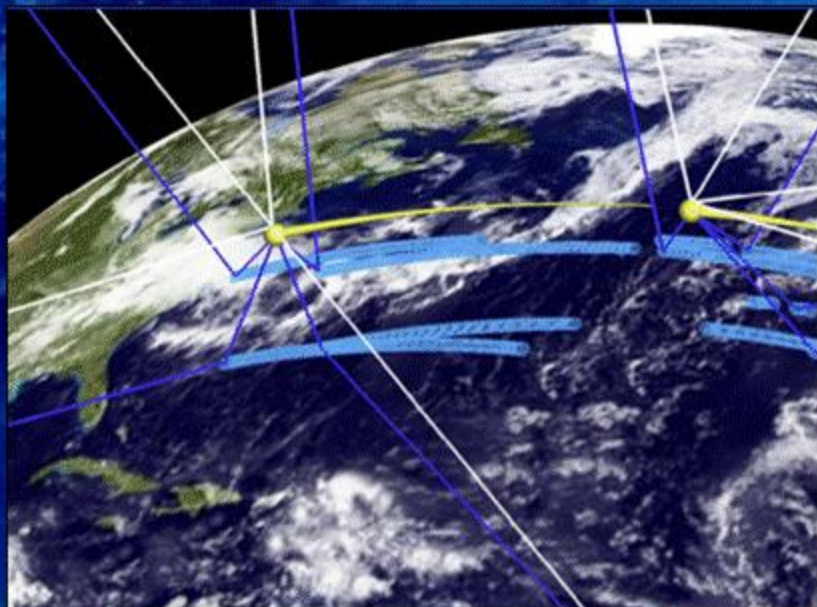
# Hurricanes and Climate Change – Expectations Versus Observations

1. Relatively minor manmade hurricane changes decades into the future
2. Huge decadal scale hurricane variations occurring today
3. Huge vulnerability issues today, which will get increasingly severe as population grows
4. Need to address vulnerability issues now (no need to invoke possible minor changes decades from now):
  - a. Improved hurricane observational network



# CYGNSS

The Cyclone Global Navigation Satellite System



## XOVWM

The Next-Generation Ocean Surface Vector Winds Mission

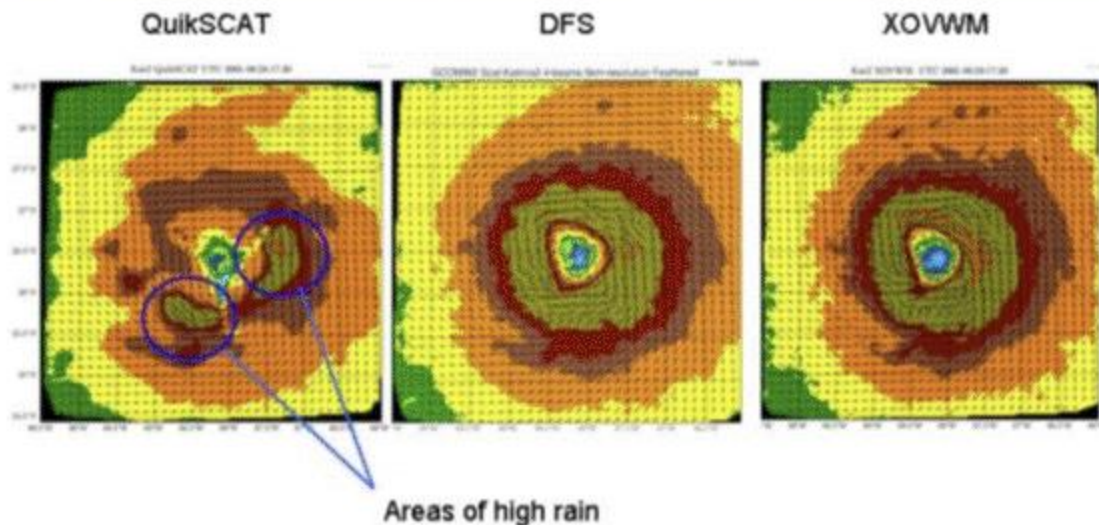


Fig. 4 Simulated QuikSCAT, DFS and XOVWM wind vector retrievals for Katrina-like hurricane.



# Hurricanes and Climate Change – Expectations Versus Observations

1. Relatively minor manmade hurricane changes decades into the future
2. Huge decadal scale hurricane variations occurring today
3. Huge vulnerability issues today, which will get increasingly severe as population grows
4. Need to address vulnerability issues now (no need to invoke possible minor changes decades from now):
  - a. Improved hurricane observational network
  - b. Improved hurricane modeling/forecasting
  - c. Improved building codes/land use
  - d. Improved evacuation/shelter plans

2005

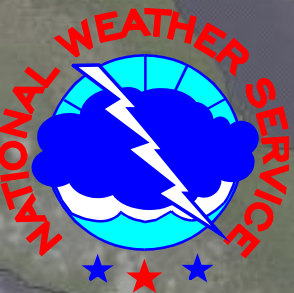
# Hurricanes and Global Warming: Expectations Versus Observations

12 June, 2015

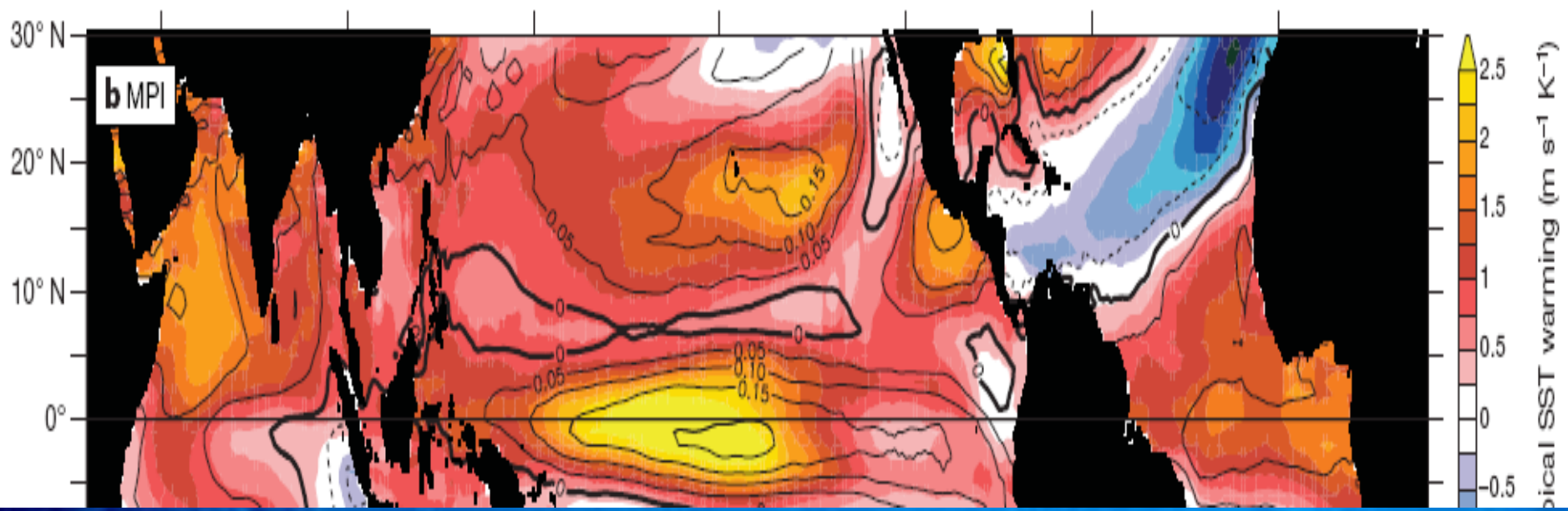
NASA Jet Propulsion Laboratory

Chris Landsea, National Hurricane Center, Miami, USA

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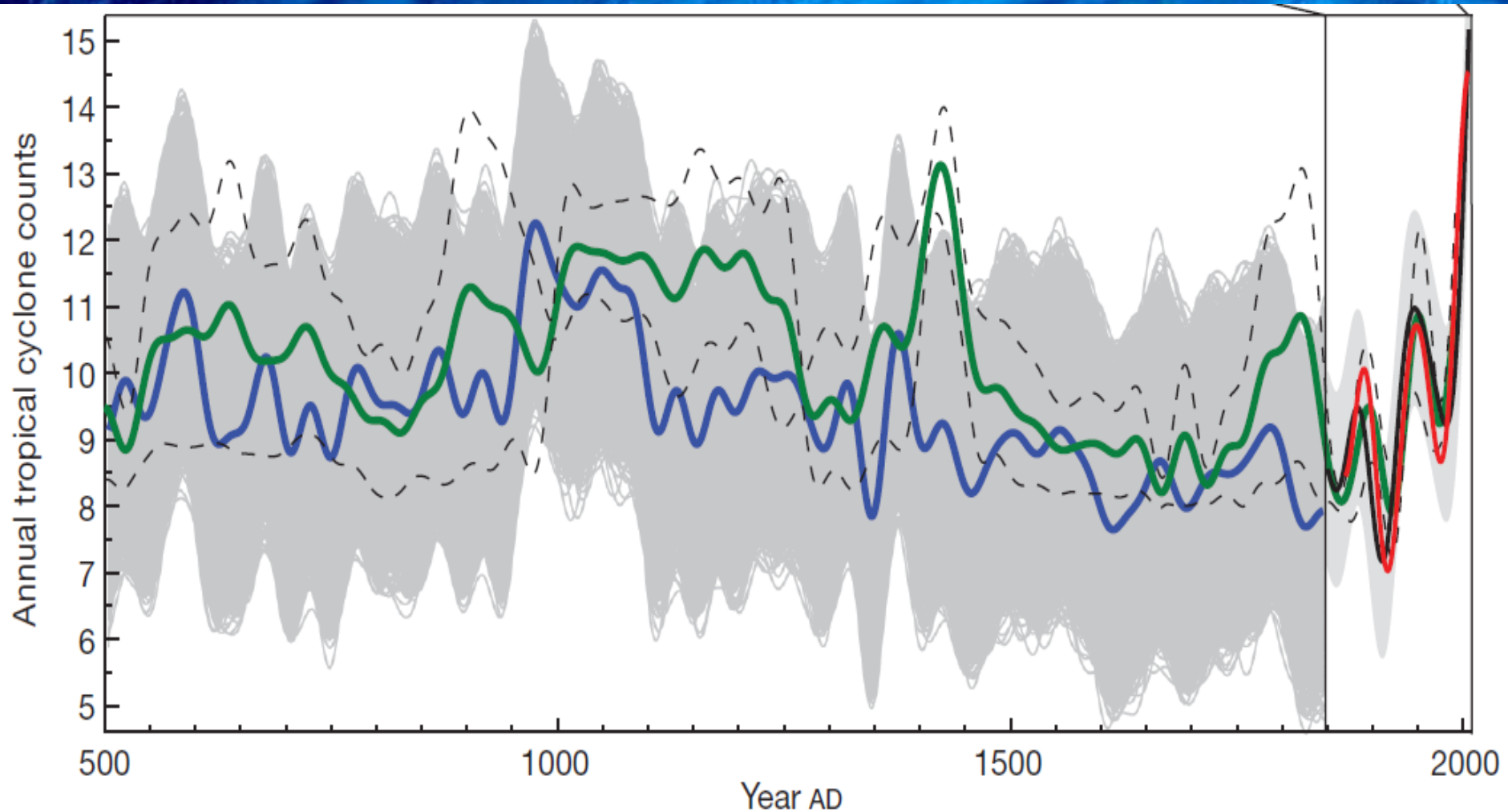






Maximum Potential Intensity Change  
Atlantic Basin: +1% stronger per °C SST change  
Vecchi and Soden (2007)

# Merging paleotempestology (sediment core records) with modern hurricane data



Mann et al. (2009)



# Landfalling Strong Hurricanes

## 1851 to 2009

